DTIC FILE COPY

(2)

AD-A216 108

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

89 12 28 070

2

AFIT/GEM/DEM/89S-8

IDENTIFICATION OF HVAC DEFICIENCIES USING ANALYSIS OF JOB ORDER DATA

THESIS

Tom M. Ellis
GS-12

AFIT/GEM/DEM/89S-8

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information is contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GEM/DEM/89S-8

IDENTIFICATION OF HVAC DEFICIENCIES USING ANALYSIS OF JOB ORDER DATA

THESIS

Presented to the Faculty of the School of Systems and Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering Management

Tom M. Ellis, B.S.

GS-12, USAF

September 1989

Acknowledgements

First, I want to thank my thesis advisor, Capt Michael Falino, for his patience with my many mistakes. This research would not have been possible without his many hours of work and expert advice.

I would like to acknowledge all the individuals at Robins AFB who never hesitated to answer my many requests for information.

I am also grateful to my faculty advisors, Lt Col James Holt and Maj Hal Rumsey, for their assistance and encouragement.

Finally, my love and thanks to my wife, Cheryl, and my daughters, for their patience and understanding; and to my brother, Gary, who was always there when I most needed support.

Tom Ellis

Table of Contents

Page

List of Figures

List of Tables

AFIT/GEM/DEM/89S-8

Abstract

The objective of this research study was to develop a systematic and objective procedure to identify HVAC deficiencies at Robins AFB, GA. Statistical analysis of HVAC repair data was used to indicate where and when HVAC deficiencies had occurred based on the potential for cost savings. The statistical models which were developed are only applicable to Robins AFB. However, the procedures used to identify HVAC deficiencies could be repeated at any base that maintains historical HVAC repair data. The research also explored the use of the procedures developed as a tool for the HVAC Evaluation Group.

The research showed that job order analysis provided a useful means for identifying HVAC deficiencies. Facility square footage and historical job order data were used to predict the expected number of job order hours within specific facility groups. These groups were established based on similarities among facilities in the HVAC job order data.

The difference between the expected hours and the actual hours was then used to prioritize HVAC deficiencies based on the potential for reducing job order hours and thus the potential for cost savings.

IDENTIFICATION OF HVAC DEFICIENCIES USING ANALYSIS OF JOB ORDER DATA

I. Introduction

Chapter Overview

Chapter One contains a brief background of the general issues which led to the need to identify Heating, Ventilating, and Air Conditioning (HVAC) deficiencies. The research objectives necessary to answer the specific problem statement are presented. Finally, the scope and limitations of this research are stated at the end of the chapter.

General Issues

The Directorate of Engineering and Services for the Air Force (HQ USAF/LEE) established HVAC Evaluation Groups in October 1982 to improve Civil Engineering's (CE) ability to meet energy reduction goals and improve the reliability of its HVAC systems (17:1). A typical HVAC Evaluation Group consists of engineers, craftsmen, and management personnel from design, construction, and operations. The Group was given the responsibility to define and prioritize HVAC system problems and to direct in-house efforts to correct these problems (19:1). In addition to HQ USAF/LEE, the Air

Force Engineering and Services Center (AFESC) also provided guidance to HVAC Evaluation Groups. According to AFESC, the core of a good HVAC improvement program is analysis of local HVAC problems and the actions required to correct them (15:2). Engineering and Services strongly emphasized the necessity for HVAC Evaluation Group members to actively identify HVAC problems and direct constructive solutions (15:4).

Specific Problem

The observations made in this section are based on the researcher's experience as a member of the HVAC Evaluation Group at Robins AFB, Georgia, since its formation in 1982. The Group has been unable to determine whether its efforts in identifying and correcting HVAC deficiencies are effective. The 2853rd Civil Engineering Squadron at Robins AFB is responsible for maintaining approximately 456 major facilities totaling 12.25 million square feet with 20,000 tons of cooling (24). The number and size of facilities make it impractical for qualified personnel to physically survey each facility to determine the condition of HVAC systems. The HVAC Evaluation Group has relied on the opinions of its members, or facility occupants, to identify and prioritize HVAC problems. Individuals have used different sets of HVAC performance indicators to form their

opinions. This approach is entirely subjective and does not guarantee corrective actions are taken on the most significant HVAC problems. Furthermore, the performance indicators used to identify the deficiency may not be the same indicators used to evaluate the corrective action. These inconsistencies do not allow the group to determine if the corrective actions being taken are most beneficial for the base HVAC systems as a whole.

Research Objective

The objective of this research was to develop a procedure to systematically and objectively identify facilities with HVAC deficiencies and prioritize them by the potential for cost savings. The results of this procedure were expressed in such a manner that the scope of the HVAC deficiencies and the effectiveness of corrective actions could be readily communicated to management. The procedure was developed and validated using data from the existing Robins AFB Civil Engineering Work Information Management System (WIMS).

Scope and Limitations

The scope of this research was to develop a systematic and objective procedure to identify HVAC deficiencies at Robins AFB. Statistical analysis of HVAC repair data was

used to indicate where and when HVAC deficiencies had occurred based on the potential for cost savings. The statistical models which were developed are only applicable to Robins AFB. However, the procedures used to identify HVAC deficiencies could be repeated at any base that maintains historical HVAC repair data. The research also explored the use of the procedures developed as a tool for the HVAC Evaluation Group.

The research was limited to HVAC job order histories in the existing WIMS database at Robins AFB, GA, for the period of time between November 1985 and July 1988. This research was not be able to establish the causes for HVAC deficiencies because of limitations in WIMS job order recording procedures. Existing procedures do not record HVAC work by individual system nor do they record the actions taken to repair the HVAC system.

II. Literature Review

Chapter Overview

This literature review presents the need for developing a procedure to identify HVAC deficiencies, the attributes such a procedure should possess, and how such a procedure should be used to manage HVAC systems.

Background in Civil Engineering

HVAC Services. Charles Braswell and Lewis Strong, the physical plant director and mechanical systems engineer for the North Carolina State University, have stated that funding required for a facility consists of construction, equipment, and operation and maintenance (5:69). Of these three areas, operation and maintenance requires the majority of the funds (5:69). The Director of Air Force Engineering and Services has also stated that operation and maintenance is the most significant life cycle costs associated with a HVAC system (18:1). As an example of funding requirements, the annual budget for mechanical systems at Robins AFB is estimated at 17-20 million dollars (2). This budget includes contract and in-house repair, maintenance, and minor construction work as well as utilities costs.

State of HVAC Systems. After visiting various bases, the Engineering and Services Center summarized their

findings of typical HVAC problems experienced at Air Force bases (14:1). The most common problems were

1. Lack of a forum to discuss and resolve obstacles to HVAC improvement.

2. Little emphasis on recurring maintenance and training.

3. Bypassed or damaged controls.

4. Temporary repairs, with no follow-up action, were used to restore system operation.

5. Inadequate technical review of facility modifications and their effect on HVAC systems.

6. Insufficient equipment for balancing HVAC air and water distribution.

7. Ineffectual design of HVAC systems.

8. Limited technical assistance for the Operations Branch.

9. Weak inspection of HVAC system construction.

10. Inadequate pre-final inspection of contract work by Contract Management led to the acceptance of malfunctioning HVAC systems. (14:3-7)

These findings demonstrate the range and complexity of issues involved in the management of HVAC resources. They also enforce the need for timely feedback and coordination between the various Civil Engineering sections responsible for HVAC systems.

HVAC Evaluation Groups. The Director of Engineering and Services recognized these issues and the need to dedicate efforts and resources to identify, prioritize, and correct HVAC deficiencies and stress the recurring maintenance program. HVAC Evaluation Groups were established in October 1982 to improve Civil Engineering's ability to meet energy reduction goals and improve the reliability of its HVAC systems (17:1). These groups consist of engineers, craftsmen, and management personnel from the design and construction sections and the operations branch. The groups have the responsibility to define and prioritize base HVAC system problems and to direct in-house efforts to correct these problems (19:1). The Engineering and Services Center outlined the necessary steps to be taken by each base to upgrade its HVAC systems and make the necessary resource and management adjustments to maintain quality HVAC service at a reasonable cost. Base Civil Engineering (BCE) became responsible for the staff and the management of this HVAC enhancement effort. HVAC deficiencies would first be identified and then prioritized by degree of need for corrective action. After the deficiencies were prioritized, Civil Engineering would take appropriate actions to correct these deficiencies (15:1-4).

Need for a Measurement

HVAC Evaluation Groups are not expected to provide all the answers, but they are expected to identify major problem areas and provide a systematic way to solve those problems (10:5). Quality groups similar to the HVAC Evaluation Group found that most of the chronic problems are being identified as a result of customer crisis rather than through in-depth analysis (11:63). Capt George G. Barksdale, a former member of the Strategic Air Command (SAC) Mechanical Equipment Maintenance Evaluation Team (MEMET), stated, in his booklet To Aspire For Excellence, the need for emphasis on product-oriented performance (3:17). Existing performance measures such as direct labor activity, delinquency rates, material backlog, and schedule compliance are process measurements and do not address the product. The product, in the case of HVAC systems, is a system which provides a controlled environment for occupancy comfort or critical equipment by satisfying facility heating and cooling loads (16:6). HVAC repair orders represent a failure of the HVAC system to satisfy these requirements. Because existing measurements are process oriented, the HVAC Evaluation Group at Robins AFB, GA, has had to rely on the opinions of its members to identify and prioritize HVAC problems. W. Edwards Deming, a well-known quality expert, has stated that these decisions should be based on accurate and timely data, not on "wishes,

hunches, or experiences" (32:96). David Acker, a professor of management at the Defense Systems Management College, used the following quote by J.L. Riggs and G.H. Felix to stress the need for measurement.

> To improve productivity you must manage.
> To manage effectively, you must control.
> To control consistently, you must measure.
> To measure validly, you must define.
> To define precisely, you must quantify. (1:23).

Measurement is the key to any improvement that may be available to solve chronic problems (6:40). The fact that measurement must come before control is a basic principle of modern management (34:64). Dean-Michael Lenane, a senior reliability manager for United Technologies, reinforces this principle when he says, "If any lesson has been learned ... it is that decisions must be based on measurable units, not opinions and conjectures" (25:23). To improve performance, an organization must assess its present performance and use the data collected as a foundation for developing improvement plans (1:26). Key performance indicators should be identified to provide the organization with the necessary feedback to monitor its progress (1:26).

Attributes of a Valid Measurement

Statistical Methods. Dean-Michael Lenane recommends that statistical methods should be used to identify waste, rather than standards or allowances. He states that

statistical methods should be applied to high cost areas to document and quantify progress. If standards and allowances are applied to performance measurement, they can create a false illusion of efficiencies (25:23). Numbers generated may appear acceptable on paper, even while waste and rework are being generated at high levels (25:23). Standards and allowances also make the acceptance of product nonconformities and inefficiency inevitable, and give management a false sense that everything is operating properly and efficiently (25:23).

Units of Measure. "Studies have shown that management is responsible for at least 85% of the quality problems encountered in any process or system" (22:23). Since the majority of quality problems are due to management, a valid measurement should be expressed in terms which management understands. Lenane states that the quality manager can use units of almost anything quantifiable to monitor or measure his efforts. But to express status or concerns to management, the units must be dollars (25:23). A cost system shows how and where money is being spent and gives management the opportunity to commit resources toward investigation of specific high cost areas (25:27). Edward Brown, the president of a corporation which specializes in

process optimization systems, concluded that "All engineering parameters can be reduced to financial measurements" (6:40).

<u>HVAC Attributes</u>. D.R. Dohrmann and T. Alereza identify several variables which affect HVAC maintenance costs in their study for the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). In their study on "Analysis of Survey Data on HVAC Maintenance Costs", the authors concluded that:

1. Average HVAC maintenance costs do not differ significantly among major geographical locations.

2. Differences in the average HVAC maintenance costs per square foot among size categories are not significant.

3. Differences in the average HVAC maintenance cost for different types of facilities are significant.

4. Differences in the average cost of HVAC maintenance are significant when facilities are classified according to their age. (9:552,556).

These variables could affect the priority placed on HVAC deficiencies when making comparisons between facilities on the basis of maintenance costs.

Features of a Job Order Measurement

Dean-Michael Lenane states that measurements should be expressed on an operation-by-operation basis (25:27). In

Civil Engineering maintenance planning, job order data provide the most tangible evidence of workload. This means job order data are absolutely essential for effective maintenance management (34:63). The proportion of job orders planned and scheduled compared to the proportion performed as emergency or special requests are proven indicators of maintenance efficiency (20:62). Additionally, planned and emergency job orders can be monitored easily and almost continuously with any good job order tracking system (20:62). Automated job order information is now available in almost all Civil Engineering squadrons (33). Emergency and urgent calls, when properly accomplished, should represent less than twelve percent of the available direct hours (3:6). A repair job done on an emergency basis requires three times more manpower, time, and money than a scheduled repair (3:6). This does not count downtime costs. These repairs also limit the manhours available to accomplish other operations and maintenance tasks. A service organization such as CE should be able to maintain an average of 90% or more compliance with the recurring maintenance schedule (3:29). Time spent on emergency and urgent job orders consistently decreases when recurring maintenance compliance and effectiveness increases (3:51).

Civil Engineering Job Order System

Air Force Regulation (AFR) 85-2, Operations Management, defines the job order system as a fast way to authorize work that does not require detailed planning. The job order system specified by AFR 85-2 consists of emergency, urgent, and routine job orders. Emergency job orders are defined as any work required to correct an emergency condition that is damaging to the mission or operational effectiveness. Urgent job orders are any work that is not classified an emergency but should be accomplished within five workdays. Routine job orders are defined as work that does not qualify as emergency or urgent work. Routine job orders should be accomplished within 30 calendar days after receiving the request or required materials (7:24).

Work performed by Civil Engineering shops is classified as either direct or indirect work. Direct work includes recurring work, emergency job orders, urgent job orders, minor construction work, routine job orders, maintenance and repair work orders, plant operations, and readiness training. Supervision, training, leave, overtime, and loaned/borrowed hours are all examples of indirect work (7:71). These work classifications demonstrate the wide range of shop responsibilities that can be adversely effected by excessive job order requirements.

Use of Measurement

To use measured data effectively, Lyle McCormick, the vice president for an Atlanta consulting firm, recommends graphing the results over some period of time so as to recognize performance trends. Along with these trends, past maintenance costs should be graphed and compared to current results. The comparison of the two costs are necessary to calculate productivity improvement and cost savings (26:194). Comparison of past performance in different areas can also identify those improvements that are obtained at the expense of performance in another area.

Interviews

Interviews were conducted to determine what types of job order data other organizations recorded and whether analysis of these data was used to identify and prioritize HVAC deficiencies. Within the Air Force, interviews were conducted with personnel at the Logistics Command Headquarters. Interviewees were selected based on sources recommended by Capt Michael Falino, an instructor of Operations Management at the School of Civil Engineering and Services. Interviews were also conducted with physical plant personnel at selected universities. Selections were based on recommendations by the Association of Physical Plant Administrators of Universities and Colleges (APPA) and

the researcher's personal experience (12). Universities were chosen because their operations closely parallel those in Civil Engineering. Universities have multipurpose facilities widely scattered throughout the campus, similar to facilities on Air Force bases.

Semi-structured interview techniques were used in telephone and personal interviews to answer the following questions:

1. Do you use an automated job order accounting system? If so, can you describe some of its major features?

2. Do you record a description of the repairs made to the HVAC equipment? Who records the description and when is it recorded?

3. Are these descriptions based on actual repairs or the customers' descriptions of the problem? How do you distinguish between these two descriptions?

4. How do you track job orders? By individual HVAC systems? By facility?

5. Do you maintain a history of job order data? If so, how much history is maintained and what is it used for?

6. How do you prioritize work to be accomplished by your mechanical shops?

7. Are you aware of anyone who uses job order analysis as a performance measurement? Is it used to set work priorities?

Interview Results

Air Force. Interviews were conducted with two personnel at Headquarters Air Force Logistics Command (AFLC). Capt Mike Schmidt and Chief Master Sergeant James Preacher in the Maintenance Engineering Division at Headquarters Air Force Logistics Command (HQ AFLC/DEMM) were interviewed concerning their work on facility infrastructures which included mechanical systems. Their work involved the development of the Facilities Infrastructure Management Aid (FIMA). This is to be an artificial intelligence system which uses integrated database and expert knowledge to provide information and recommendations on the base infrastructure condition. The study they were conducting did not relate directly to this research and they were not aware of any work being done on job order analysis. Capt Schmidt did suggest the possibility of developing a method which would interface with CE Computer Aided Drafting and Design (CADD) systems as a means of quickly identifying specific HVAC equipment with a particular job order (30).

Dave Johnston, a Work Information Management System (WIMS) programmer at HQ AFLC, was also interviewed. He said that repair descriptions could be entered by the shop when the job order was closed out rather than using the customer's description of the problem. The decision to do

so is entirely a base-level decision. However, he thought there would be a big problem with compliance by the shops, considering the difficulty in getting accurate time accounting now. He also raised doubts about the accuracy of the data kept on the WIMS histories. As to the level of tracking of job orders in a database, he had considered tracking job orders by the equipment rather than the facility, but thought this would result in an unmanageable database which required too much memory. He was not aware of anyone analyzing job orders as a means of identifying HVAC deficiencies (21).

Universities. Interviews were conducted with physical plant personnel from three universities. Cliff Belt, the director for special projects at Rochester Institute of Technology (RIT) in New York, discussed the job order recording procedures they currently had in use. Facilities are inventoried by room number, and job orders are tracked by the room numbers. This scheme is used to schedule and order materials for maintenance projects such as carpet and paint by room instead of facility. This prevents closing a facility or large areas of it for maintenance projects. One shortcoming he discussed was the fact that this scheme gave no indication of function, organization, traffic, location, etc. RIT does identify individual HVAC systems in their database; descriptions of repairs are entered after the work

is completed using approximately 100 repair codes. When job orders are initially called in by the customer, approximately 20 complaint codes are used as a preliminary means of assigning the job order to a shop. They were in the process of developing their database and did not have job order history data available for analysis. They were not aware of anyone using job order analysis (4).

James Sherrill, Senior Management Analyst at the University of Tennessee in Knoxville, said they were in the process of developing an automated job order system for their HVAC systems. Carla Wyrick, the programmer for this new system, was interviewed for details. The system would use equipment serial numbers to identify individual HVAC equipment on job orders. This would allow them to link repairs to specific HVAC equipment. The system procedures would also require that repair codes/descriptions be entered after the work was accomplished. They were not using job order analysis, and were not aware of anyone who was using it (31).

Roger Hayes, the Chief of Energy Management at the University of North Carolina, was interviewed concerning their job order system. They did not identify individual HVAC equipment or maintain job order history files. They used customer descriptions rather than assigning repair codes to a job order. Their emphasis was on recurring

maintenance, particularly maintenance of HVAC controls. He did not know of anyone using job order analysis (13).

Air Force Civil Engineering appears to be well ahead of these Universities in the development of an automated job order system. For the most part, these universities were in the process of defining the database characteristics and no historical job order data was available for analysis yet. However, two universities did have procedures for identifying individual equipment and recording the actual repairs in their job order systems, which could possibly help to prioritize HVAC deficiencies.

Conclusions

This chapter discussed the need to identify and prioritize HVAC problems using quantifiable measurement of key performance indicators. Job order data provides the most tangible evidence of workload and job order data can be obtained easily and continually. Job order analysis provides an indication of the capability of the HVAC system to perform its job. The analysis of job orders should be statistical rather than in the form of standards and allowances. The results of the analysis should be expressed in terms of dollars to be easily understood by management. When dealing specifically with mechanical systems, some variables which affect HVAC maintenance costs, and therefore

performance, are facility square footage, function, and age. Any comparisons of HVAC performance between facilities should account for the influence of these variables. Past performance should be graphed to recognize trends and diagnose chronic problems. Current performance should then be graphed to evaluate specific and overall improvement.

The interviews, although not extensive by any means, did not reveal anyone who was using job order to prioritize HVAC deficiencies. These interviews did show some job order recording procedures that might be beneficial if incorporated into the Civil Engineering WIMS. One example is the use of codes which make a distinction between customer complaints and descriptions of the actual repairs. Having the capability to track job orders by specific equipment rather than facility number would help to focus the efforts to correct HVAC deficiencies.

III. Methodology

Chapter Overview

This chapter describes the general procedures used to answer the research objective outlined in Chapter One. A description of the population and sample, the data collection procedures, and data analysis techniques are discussed. Finally, graphing requirements for the procedure are described.

General Procedures

Although no one was found to be using job order analysis, the literature review strongly suggests that such analysis would provide an appropriate method for identifying and prioritizing HVAC deficiencies. As pointed out by the interviews conducted, the Air Force WIMS is a well-established automated job order accounting system. Two job order variables are readily obtained from the WIMS database. These variables are the number of job orders and total hours for each job order. Of these two variables, job order hours would appear to be an excellent candidate for job order analysis.

Job order hours can be easily converted to dollar figures. This satisfies the goal of presenting information to management in terms of dollars which was also discussed

in the literature review. Excessive job order hours would also generally indicate that an HVAC deficiency exists. The problem is then determining what constitutes excessive job order hours. To accomplish this, it was necessary to find a method for predicting the expected hours so they could be compared to the actual hours.

Because job orders in the WIMS are recorded by facility, comparisons of HVAC job order hours were made on a facility basis. The literature review established that facility age, square footage, and type could have an effect on comparisons of repair costs among facilities. Therefore, it was necessary to evaluate the effect of these facility variables on the ability to predict expected job order hours.

The difference between the expected facility hours and the actual facility hours was used to prioritize HVAC deficiencies based on the potential for reducing job order hours and thereby saving dollars. The facilities with the largest difference in actual and expected hours were ranked highest because they had a higher probability for the largest savings if corrective actions were taken.

Population and Sample

The population of concern consisted of monthly HVAC job order hours and job order totals for all facilities at

Robins AFB with mechanical cooling. The sample was limited to those facilities in the WIMS database at Robins AFB. The sample was further limited by eliminating the following WIMS data entries based on information from the Robins AFB Real Property Inventory Detail List:

1. All facilities demolished during time period studied.

2. All facilities completed after the start of the time period studied.

3. All family housing units (housing maintenance is contracted out at Robins AFB).

4. All portable facilities.

5. All facilities for which work is tracked by Collection Work Order Numbers (CWON) such as steam distribution piping, steam pits, and other work not done on a specific facility. The CWON was obtained from the BCE Collection Work Order List.

6. All central chilled water and steam plants.

7. All facilities with only window air conditioning units.

Based on the researcher's knowledge of facilities on Robins AFB, the assumption was made that any facility with heating also had some part of the facility cooled, and no facility with HVAC equipment had zero job orders in the time period studied.

Data Collection

Four WIMS job order data files were obtained from Robins AFB. These files included data for the period of 1 November 1985 to 31 July 1988. The data for the months of April 1986 and September 1986 were missing from the files.

WIMS utility programs were used to combine these data files into a single file and to eliminate duplicate data entries. These programs were then used to create a new data file, which reduced the fields in the original database to the facility number, job order number, year and month completion date, and total job order hours. The cases were also reduced to only those job orders that had a Do-It-Now (DIN) truck number or shop cost center code used by the heating, refrigeration, or controls shops. The WIMS utility programs proved to be very unwieldy for this type of data manipulation. A detailed description of the problems experienced and how they were dealt with are presented in Appendix B.

It was necessary to obtain monthly subtotals of the job order hours by facility since subsequent data analysis was made on a monthly basis. Several unsuccessful attempts were made to obtain this information in a suitable format using the WIMS utilities. Details of these attempts are also discussed in Appendix B. Eventually, it was necessary

to write a COBOL program to overcome the problems experienced with the WIMS utilities.

Mark Klosterman, from the Engineering and Services Center, wrote a COBOL program (see Appendix C) which provided a comma delimited data file with the facility number, completion date, job order hour monthly subtotals, and the total number of job orders completed in a facility each month (23). The program also sorted by facility with a secondary sort on the completion date. The resulting data file was then written as a continuous string to DOS format using a Wang PC and Wang VSACCESS software. The file was written to ASCII format for use on the AFIT VMS mainframe computer because WIMS did not have the necessary statistical software for this research. Although the VMS mainframe computer was used for this research, the same analysis could be accomplished on any personal computer with adequate statistical software and memory capacity.

The final data file contained four fields (facility number, hours, completion date, and job order count) with data for the 351 facilities which had at least one job order charged to them by the heating, refrigeration, or control shops during the 33 months studied.

File Transformations

At this point a Basic program (see Appendix D) was written to convert the data from a string to a table. This Basic program also inserted zeros for the months in which there were no job orders recorded rather than recording them as missing values. Variations of this Basic program were used to create three files by facility number; one for the total hours/month, one for the number of job orders/month and one for the ratio of total hours to number of job orders for each month.

These three files were then imported to "Quattro", a spreadsheet program. The spreadsheet was used to eliminate the following data entries

1. All facilities demolished during time period studied.

2. All facilities completed after the start of the time period studied.

3. All family housing units (housing maintenance is contracted out at Robins AFB).

4. All portable facilities.

5. All facilities for which work is tracked by Collection Work Order Numbers (CWON) such as steam distribution piping, steam pits, and other work not done on a specific facility. The CWON was obtained from the BCE Collection Work Order List.

6. All central chilled water and steam plants.

7. All facilities with only window air conditioning units.

After this reduction, 181 of the 351 facilities in the original data file remained. The columns for the months of April 1986 and September 1986 were eliminated because these months were missing in the original WIMS data files. The accuracy of the resulting database was then verified by checking the subtotals obtained from the original data files for Building 640 to ensure that no data was lost by reducing the data from the original Robins AFB files. Building 640 was selected because it contained a high number of job orders for each month in the database.

Additional Data

Averages. The thirty-one month average was computed for each facility in the three data files and the results were combined into a single file. The age and size of the facilities were then entered into the data file. The hours/month/square foot, hours/month/years of age, job orders/month/square foot, job orders/month/years of age, and hours/job order were calculated and entered into the database. This data was used in the preliminary statistical analysis of the relationships between variables.

In addition, quarterly moving averages for the hours and number of job orders were calculated. Since the Robins AFB HVAC Evaluation Group normally meets monthly, moving averages were used so the measurements established as a result of this research could be expressed on a monthly basis. A quarterly average was used to smooth the repair data so HVAC deficiencies would not be identified based on a single random occurrence. The BASIC program shown in Appendix E was used to produce the quarterly moving averages for the hours/month, job orders/month, and hours/job order of each facility.

Facility Type. The type of each facility was recorded in the database, based on the first two digits of the Real Property Category Codes as defined in Air Force Manual (AFM) 86-2, Standard Facility Requirements (8:1-30). The first two digits of the category codes define major classes of facilities. The facilities were assigned to the fourteen facility categories shown in Table I where (n) is the number of facilities in the database for each category.

Data Analysis Techniques

This section describes the techniques used to evaluate the effects of facility square footage, age, and type on the ability to predict job order hours.

Table I. Initial Facility Categories

Category Code	Type of Facility	Number (n)
12	Liquid Fueling and Dispensing	2
13	Telecommunications, Navigational Aids, Airfield Lighting	4
14	Land Operational Facilities	16
17	Training Facilities	7
21	Maintenance Facilities	59
22	Production Facilities	1
44	Covered Storage Facilities	17
51	Hospital Facilities	2
61	Administrative Facilities	23
72	Dormitories, OQs, and Dining Halls	16
73	Personnel Support and Service Facilities	12
74	Welfare and Recreational - Interior	20
75	Welfare and Recreational - Outdoor	1
83	Sewage and Waste Facilities	1
	Total	181

Scatterplots. Scatterplots of facility age and square footage versus all quantitative variables and hours versus job orders were used as a preliminary visual check to identify linear relationships between variables. These techniques were not used to evaluate the effect of facility type because it is a nominal variable.

Correlations. Correlations and descriptive statistics were computed for all variables except facility number and type. Correlations for these two nominal variables would be meaningless. Correlations were used to confirm the selection of independent variables which had a strong relationship with job order hours. These variables were later used to predict job order hours.

Isolation of Different Facility Groups.

Frequency Histograms. Frequency histograms were used to determine the range of quantitative variables as well as where they clustered most heavily. The histograms were also used to check for normal distributions. Based on this preliminary check, variables with a normal distribution were selected for use in the analysis of variance (ANOVA) and multiple comparison analysis to establish facility groups.

Facility Type. The facility categories, shown in Table I, were used to group facilities with similar HVAC functions. Some categories had as few as one facility in them and would not be of any use in statistical analysis. To provide initial facility groups with at least fifteen facilities in each group, the categories were further reduced to six groups. The fourteen categories were placed into six groups based on the researcher's knowledge of typical HVAC functions within these categories. The resulting facility groups are shown in Table II.

Analysis of Variance. The Statistical Analysis System (SAS) ANOVA procedure (see Appendix F) was used to test the preliminary facility group means to determine if the difference between the means was statistically significant. Statistician Lyman Ott provides the procedures required for an ANOVA in his book, An Introduction to

Table II. Preliminary Facility Groups

Category Code	Facility Group	Number
	GROUP I	23
12	Liquid Fueling and Dispensing	
13	Telecommunications, Navigational Aids, Airfield Lighting	
14	Land Operational Facilities	
83	Sewage and Waste Facilities	
	GROUP II	60
21	Maintenance Facilities	
22	Production Facilities	
	GROUP III	42
17	Training Facilities	
61	Administrative Facilities	
73	Personnel Support and Service Facilities	
	GROUP IV	17
44	Covered Storage Facilities	
	GROUP V	18
51	Hospital Facilities	
72	Dormitories, OQs, and Dining Halls	
	GROUP VI	21
74	Welfare and Recreational - Interior	
75	Welfare and Recreational - Outdoor	
	Total	181

Statistical Methods and Data Analysis. The assumptions necessary for an ANOVA are independent random samples from normally distributed populations with a common population variance. The assumption of normality is not critical because the Central Limit Theorem applies to means. Non-normality will not affect the results of an ANOVA unless the distribution is severely skewed and the sample sizes are

small. The assumption of equal variances is also less critical when the sample sizes are considerably different (27:401-427). If the difference in the group means is found to be statistically significant, it can be stated, within certain confidence limits, that at least one of the means must be from a different population.

Multiple Comparisons. Multiple Comparison procedures were used to determine which means differed significantly from each other after the ANOVA rejected the null hypothesis of equal means. This analysis was also performed using SAS statistical software (see Appendix F). The particular multiple comparison procedure chosen for this research was the Fisher Least Significant Difference (LSD) procedure. The LSD was chosen because it is one of the least conservative procedures, being very sensitive to differences in the means (28). The benefits of being able to identify a problem facility, which would otherwise be obscured by facilities with higher expected repair costs,outweigh the potential for falsely declaring a separate group. It was also chosen because it could be used for means with different sample sizes (27:442).

Prediction of Job Order Hours. Once the effects of facility age, square footage, and type were understood, linear regression was used to predict an expected value for average quarterly job order hours for each facility. The

predictor variables used to predict the job order hours were those variables identified by the scatterplots and confirmed by the correlations. The assumptions for linear regression are independent samples and a linear relationship between the criterion and predictor variables (29).

The regression model was then tested for overall fit and contribution to fit by the predictor variable. In addition to the previous assumptions, the assumptions for these tests are independent, normally distributed errors with a common variance, and a mean of zero (29).

Identification of HVAC Deficiencies

The residual hours for each facility were calculated by subtracting the expected value for job order hours from the actual value of job order hours. To identify the facilities with the most critical HVAC deficiencies, an upper limit was calculated to identify excessive residual hours. As suggested in the Attributes section of the literature review, the upper limit was established using statistical methods rather than setting a standard.

Because the residuals were normally distributed with a mean of zero, probability values for the (z) distribution curve were used to determine the significance of a residual. An upper limit for the residuals was calculated using a right tailed (z) critical value, the standard deviation of

the residuals for each group, and an alpha value of 0.01. This high confidence level was chosen to limit the number of facilities identified to a number which the Robins AFB HVAC Evaluation Group could reasonably expect to investigate.

Those facilities whose positive residual value exceeded the upper limit were identified as having excessive HVAC job order hours and therefore excessive deficiencies for that particular month. Because residuals represent the potential for improvement, ranking facilities within groups based on residual values provided a prioritized listing of facilities with the largest potential for savings, if corrective actions were taken.

Graphs

After the top two facilities with excessive residuals from each group were identified, the residuals for those facilities were graphed for the period of time under study. The residuals were converted to dollars based on the shop rate established for the heating, refrigeration, and controls shops during the period of time being graphed. The upper residual limit, computed using the standard deviation of the residuals and the (z) critical value, was also shown on the graph. These graphs were used to evaluate trends in job order hours over the thirty-three month period for which data was collected.

Retest

Once the procedure for identifying HVAC deficiencies was established, it was repeated for new job order data obtained from Robins AFB. Completed job order data, from 15 March 1989 through 15 June 1989, was collected for this purpose. The actual hours were calculated and then compared to the predicted values for each facility group to determine if the hours were still excessive.

To evaluate the effects of corrective actions, information on mechanical improvements for these six facilities were also obtained from Robins AFB. This information included mechanical contract projects and HVAC Enhancement Team improvements completed since July 1988. The data collected for the initial analysis ended in July 1988.

IV. Analysis and Discussion

Chapter Overview

This chapter contains the results of analyzing the historical job order data from Robins AFB and the results of retesting current job order data from Robins.

Preliminary Data Analysis

Scatterplots. The plot of average hours/month versus average job order/month, shown in Figure 1, revealed a highly linear relationship.

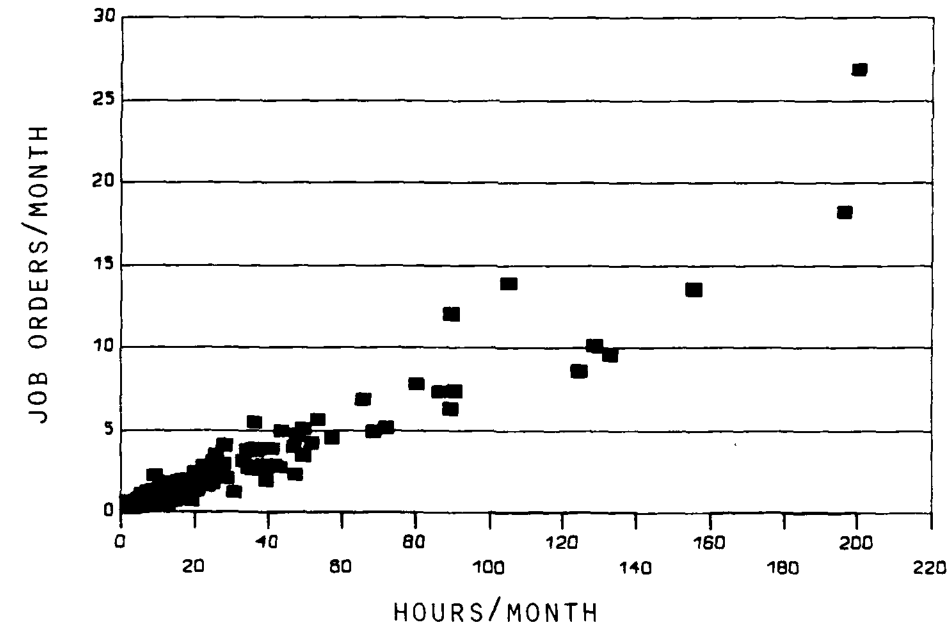


Figure 1. Scatterplot of Hours versus Job Orders

The remaining scatterplots for all quantitative variables are shown in Appendix G. The square footage appeared to have a linear relationship with both average hours/month and average job orders/month. The scatterplot of hours/job order appeared to be normally distributed when plotted against square footage. The other scatterplots did not reveal any recognizable relationships. Correlations were used to confirm the linear relationships that were shown by the scatterplots.

Correlations. The correlation matrix for these same variables, computed with "Statistix", is shown in Table III where

AGE = facility age
SF = facility square footage
HR = average hours/month
HRSF = hours/square foot
JO = number of job orders
JOSF = job orders/square foot
HRJO = hours/job order
HRAGE = hours/facility age
JOAGE = job orders/facility age

The correlation matrix for the quantitative variables demonstrated that facility age had very poor correlations with the other variables. This was not unexpected because the facility ages on an Air Force base usually do not give an indication of the age of the HVAC equipment. The age of the HVAC equipment, not facility age, would normally be expected to relate strongly to the job order hours.

Table III. Correlation Matrix for Building Variables: Single Group (n=181)

	AGE	SF	HR	HRSF	JO	JOSF	HRJO	HRAGE	JOAGE
AGE	1.00								
SF	0.18	1.00							
HOUR	0.17	0.64	1.00						
HRSF	-.07	-.30	0.02	1.00					
JO	0.17	0.61	0.95	0.01	1.00				
JOSF	-.14	-.32	-.04	0.83	0.02	1.00			
HRJO	0.05	0.17	0.22	0.30	0.06	-.10	1.00		
HRAGE	-.28	0.41	0.69	-.00	0.61	-.07	0.21	1.00	
JOAGE	-.29	0.40	0.69	-.01	0.67	-.01	0.08	0.97	1.00

The correlation between hours/month and job orders/month had the highest correlation with a correlation coefficient (r) of 0.95. Other apparently significant correlations were hours/month and square footage with a (r) value of 0.64 and jcb orders/month and square footage with a (r) value of 0.61. Other high correlations between variations of the variables of hours/month and job orders/month are due to the high correlations between hours and job orders. Therefore these correlations do not offer any additional information.

Based on these correlations, facility square footage was selected for use in a linear regression analysis to predict expected job order hours. Although the job orders/month showed a strong relationship to hours, it was not used in the regression analysis because it is a random variable. The job orders/month would have to be determined after the fact, where the facility square footage would be

known. Job orders/month also had a high correlation to square footage. Using predictor variables with a high correlation to each other would have adversely affected the accuracy of the regression models used to predict job order hours.

Isolation of Different Facility Groups

Frequency Histograms. Frequency histograms were first constructed for the average hours/month and the average job orders/month. When these graphs, shown in Appendix H, did not reveal a normal distribution the variables were divided by facility square footage and facility age in an attempt to normalize the data. The resulting histograms for these new variables are also shown in Appendix H. Facility age and square footage had very little effect on the original distributions for average hours/month or job orders/month. Based on the poor linear relationship and negligible effect on the job order hour distribution, facility age was not used for further analysis.

The final histogram, for the ratio of hours to job orders, is shown in Figure 2. This histogram did reveal a normal distribution. Based on this preliminary check, the hours/job order variable was selected for use in the ANOVA and multiple comparison analysis to establish facility groups.

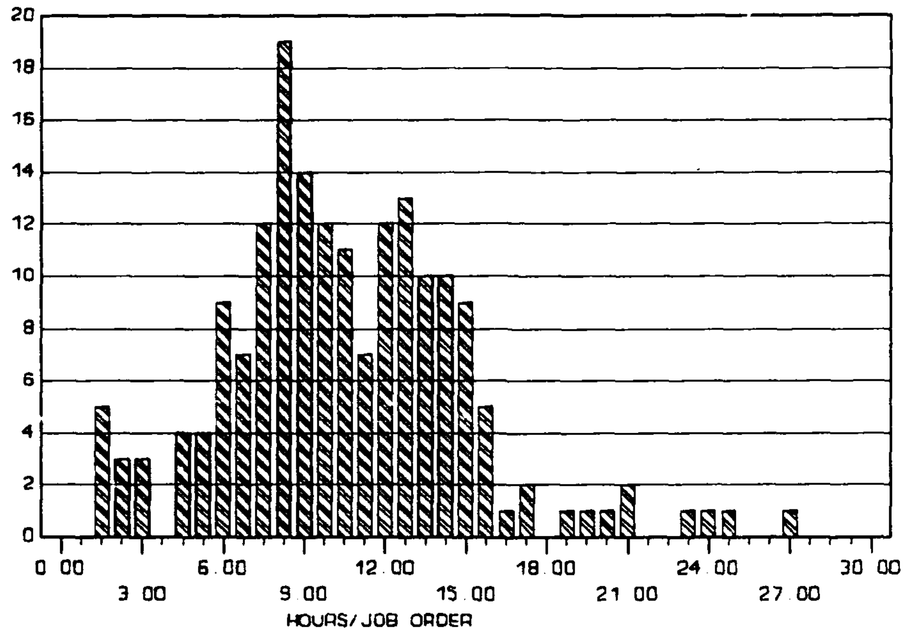


Figure 2. Frequency Histogram of Hours/Job Order

ANOVA and Multiple Comparisons. Of the variables available from the original group, hours/job order was the only one which satisfied the assumptions necessary for an Analysis of Variance (ANOVA). The hours/job order data for each facility was paired with the one of the six facility groups obtained from Table II in Chapter III. A SAS ANOVA and LSD Comparison of Means program (see Appendix F) was used to evaluate the variability among the group means for hours/job order in comparison to the means within the groups. The results of this analysis are shown in Figure 3.

SAS
ANALYSIS OF VARIANCE PROCEDURE
CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
BLDGRP	6	1 2 3 4 5 6

NUMBER OF OBSERVATIONS IN DATA SET = 181

ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: HOURS PER JOB ORDER (HRPJO)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	5	357.75851366	71.55170273	3.89
ERROR	175	3220.04927971	18.40028160	PR > F
CORRECTED TOTAL	180	3577.80779337		0.0023

R-SQUARE	C.V.	ROOT MSE	HRPJO MEAN
0.099994	42.4555	4.28955494	10.10364641

SOURCE	DF	ANOVA SS	F VALUE	PR > F
BLDGRP	5	357.75851366	3.89	0.0023

T TESTS (LSD) FOR VARIABLE: HRPJO
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE
ALPHA=0.05 DF=175 MSE=18.4003
CRITICAL VALUE OF T=1.97361
LEAST SIGNIFICANT DIFFERENCE=2.424
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=24.3949
MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

T GROUPING		MEAN	N	BLDGRP
	A	11.658	60	2
B	A	10.771	17	4
B	A	10.762	23	1
B	C	9.083	42	3
	C	8.206	21	6
	C	8.049	18	5

Figure 3. Results of ANOVA and LSD Comparison of Means for Six Facility Groups

The ANOVA null hypothesis of equal population means between the groups was rejected with a (p) value of 0.0023. The LSD Comparison of Means analysis revealed three significantly different groups. Based on this analysis, the final facility groups were formed as shown in Table IV.

Table IV. Final Facility Groups

Category Code	Facility Group	Number
	GROUP I	82
12	Liquid Fueling and Dispensing	
13	Telecommunications, Navigational Aids, Airfield Lighting	
14	Land Operational Facilities	
17	Training Facilities	
44	Covered Storage Facilities	
61	Administrative Facilities	
73	Personnel Support and Service Facilities	
83	Sewage and Waste Facilities	
	GROUP II	60
21	Maintenance Facilities	
22	Production Facilities	
	GROUP III	39
51	Hospital Facilities	
72	Dormitories, OQs, and Dining Halls	
74	Welfare and Recreational - Interior	
75	Welfare and Recreational - Outdoor	

The ANOVA and Comparison of Means analysis was repeated for these three facility groups and the results shown in Figure 4. The ANOVA null hypothesis of equal population means was rejected with a (p) value of 0.0004. The LSD analysis showed three significantly different facility groups and no further facility groupings were produced.

```
                              SAS
                    ANALYSIS OF VARIANCE PROCEDURE
                  CLASS LEVEL INFORMATION

                CLASS      LEVELS     VALUES
                 BLDGRP       3        1 2 3
                 NUMBER OF OBSERVATIONS IN DATA SET = 181


                    ANALYSIS OF VARIANCE PROCEDURE
DEPENDENT VARIABLE: HOURS PER JOB ORDER (HRPJO)

SOURCE     DF    SUM OF SQUARES      MEAN SQUARE      F VALUE
MODEL       2     299.51106850      149.75553425       8.13
ERROR     178    3278.29672487       18.41739733       PR > F
CORRECTED
TOTAL     180    3577.80779337                         0.0004

R-SQUARE        C.V.         ROOT MSE             HRPJO MEAN
0.083714      42.4753       4.29154953           10.10364641

SOURCE        DF         ANOVA SS       F VALUE     PR > F
BLDGRP         2      299.51106850      8.13        0.0004

                     T TESTS (LSD) FOR VARIABLE: HRPJO
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR
RATE, NOT THE EXPERIMENTWISE ERROR RATE
                    ALPHA=0.05   DF=178   MSE=18.4174
              CRITICAL VALUE OF T=1.97338
              LEAST SIGNIFICANT DIFFERENCE=1.6143
WARNING: CELL SIZES ARE NOT EQUAL.
HARMONIC MEAN OF CELL SIZES=55.043
MEANS  WITH  THE  SAME  LETTER  ARE  NOT  SIGNIFICANTLY
DIFFERENT.

   T        GROUPING              MEAN       N   BLDGRP
                 A               11.658     60     2

                 B                9.904     82     1

                 C                8.134     39     3
```

Figure 4. Results of ANOVA and LSD Comparison of Means for Three Facility Groups

Prediction of Job Order Hours

Correlations. Facility square footage was the only nonrandom variable with a statistically significant correlation with hours/month. This correlation was computed again for the three facility groups which had been established and the results are shown in Table V. The correlation for Group 1 was lower with a correlation coefficient of 0.63. The Group 2 correlation was improved with a coefficient of 0.91. Group 3 showed improvement with a coefficient of 0.76.

As discussed in Chapter III, quarterly moving averages were used to smooth the randomness of the data and to allow the results of any further analysis to be expressed on a monthly basis. The correlations for the quarter average hour/month and square footage are shown in Table VI for the same facility groups. The correlation coefficients computed for the quarter figures were lower than those for the overall average figures but they had a higher statistical significance due to the increased sample size.

This analysis shows that square footage continued to have a strong relationship to hours after the facilities were assigned to the final three groups. This relationship remained strong for the quarterly moving averages. Based on the analysis to this point, facility square footage was the only variable used for linear regression.

Table V. Correlation Matrix for Building Variables: Three Groups

Group 1 (n=82)

	AGE	SF	HR	HRSF	JO	JOSF	HRJO	HRAGE	JOAGE
AGE	1.00								
SF	0.16	1.00							
HR	0.11	0.63	1.00						
HRSF	-.12	-.38	-.13	1.00					
JO	0.15	0.56	0.96	-.13	1.00				
JOSF	-.17	-.40	-.18	0.83	-.14	1.00			
HRJO	-.04	0.25	0.21	0.33	0.04	-.08	1.00		
HRAGE	-.35	0.38	0.68	-.10	0.54	-.17	0.27	1.00	
JOAGE	-.32	0.40	0.76	-.12	0.68	-.14	0.15	0.96	1.00

Group 2 (n=60)

	AGE	SF	HR	HRSF	JO	JOSF	HRJO	HRAGE	JOAGE
AGE	1.00								
SF	0.23	1.00							
HR	0.24	0.91	1.00						
HRSF	-.15	-.21	-.04	1.00					
JO	0.23	0.93	0.98	-.08	1.00				
JOSF	-.24	-.22	-.13	0.77	-.01	1.00			
HRJO	0.09	0.05	0.16	0.40	0.05	-.13	1.00		
HRAGE	-.23	0.56	0.66	-.03	0.66	-.08	0.08	1.00	
JOAGE	-.27	0.52	0.58	-.06	0.61	-.05	-.03	0.98	1.00

Group 3 (n=39)

	AGE	SF	HR	HRSF	JO	JOSF	HRJO	HRAGE	JOAGE
AGE	1.00								
SF	-.03	1.00							
HR	0.01	0.76	1.00						
HRSF	0.17	0.02	0.54	1.00					
JO	0.14	0.68	0.95	0.53	1.00				
JOSF	0.10	-.02	0.54	0.88	0.65	1.00			
HRJO	0.15	0.23	0.38	0.60	0.22	0.23	1.00		
HRAGE	-.18	0.77	0.90	0.42	0.78	0.37	0.40	1.00	
JOAGE	-.21	0.74	0.88	0.42	0.85	0.48	0.27	0.96	1.00

Table VI. Correlation Matrix for Quarter Variables: Three Groups

Group 1 (n=2378)

	SF	HRS	PRED	RESID
SF	1.0000			
HRS	0.5340	1.0000		
PRED	1.0000	0.5340	1.0000	
RESID	0.0000	0.8455	0.0000	1.0000

Group 2 (n=1740)

	SF	HRS	PRED	RESID
SF	1.0000			
HRS	0.7727	1.0000		
PRED	1.0000	0.7727	1.0000	
RESID	0.0000	0.6347	0.0000	1.0000

Group 3 (n=1131)

	SF	HRS	PRED	RESID
SF	1.0000			
HRS	0.6275	1.0000		
PRED	1.0000	0.6275	1.0000	
RESID	0.0000	0.7786	0.0000	1.0000

Linear Regression. Linear regression analysis was selected after attempts to prioritize facilities based on the probability distribution of their job order hours failed. The hours both as a single group and as three groups did not follow any commonly known distribution curve. When empirical distributions were developed from the data, their confidence limits identified facilities based in large part due to the facility square footage. Ranking facilities based on job order hours alone produced a listing where only the largest facilities were identified as having HVAC deficiencies. In an attempt to correct this problem, the

facilities were ranked by hours/square foot. This list identified only the smallest facilities where even a few job order hours would result in a large hour/square foot ratio. Corrective actions on these small facilities, whose total job order hours are insignificant relative to other facilities, does not provide the best opportunity for savings. Probability distributions for job order hours failed to identify those facilities with the largest potential for cost savings. Linear regression accounted for the effect of facility square footage and was possible because facility square footage was shown to have a strong linear relationship to job order hours.

A simple linear regression was performed for each facility group to determine the expected quarterly average hours (EQAH) using facility square footage (SF) as the predictor variable. The results of the regression analysis are shown in Figures 5 to 7. The regression model for Group 1 (Figure 5) was

$$EQAH = (.000134 \times SF) + 10.72$$

The overall fit of this model was statistically significant with a (p) value less than 0.01. The regression model for Group 2 (Figure 6) was

$$EQAH = (.000395 \times SF) + 7.81$$

UNWEIGHTED LEAST SQUARES LINEAR REGRESSION OF HOURS

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	10.721	6.7362E-01	15.92	0.0000
SF	1.3444E-04	4.3674E-06	30.78	0.0000

CASES INCLUDED	2378	MISSING CASES	0
DEGREES OF FREEDOM	2376		
OVERALL F	947.6	P VALUE	0.0000
ADJUSTED R SQUARED	0.2848		
R SQUARED	0.2851		
RESID. MEAN SQUARE	823.9		

DESCRIPTIVE STATISTICS

VARIABLE	MEAN	S.D.	N	MEDIAN	MINIMUM	MAXIMUM
HOURS	20.81	33.94	2378	8.670	0.000	430.0
PRED	20.81	18.12	2378	12.76	10.82	98.37
RESID	1.927E-08	28.70	2378	-7.688	-97.70	355.3

Figure 5. Results of Linear Regression for Group 1 Quarterly Moving Averages

The overall fit of this model was statistically significant with a (p) value less than 0.01. The regression model for Group 3 (Figure 7) was

$$EQAH = (.00146 \times SF) - 3.99$$

The overall fit of this model was statistically significant with a (p) value less than 0.01.

UNWEIGHTED LEAST SQUARES LINEAR REGRESSION OF HOURS

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	7.8091	7.9123E-01	9.87	0.0000
SF	3.9453E-04	7.7732E-06	50.76	0.0000

CASES INCLUDED	1740	MISSING CASES	0
DEGREES OF FREEDOM	1738		
OVERALL F	2.576E+03	P VALUE	0.0000
ADJUSTED R SQUARED	0.5969		
R SQUARED	0.5971		
RESID. MEAN SQUARE	852.1		

DESCRIPTIVE STATISTICS

VARIABLE	MEAN	S.D.	N	MEDIAN	MINIMUM	MAXIMUM
HOURS	26.55	45.98	1740	7.520	0.000	438.1
PRED	26.55	35.53	1740	15.35	8.401	241.9
RESID	7.634E-09	29.18	1740	-8.287	-149.6	286.2

Figure 6. Results of Linear Regression for Group 2 Quarterly Moving Averages

The contribution to fit by the facility square footage does not require a separate test when computing a linear regression with one independent variable (29). Therefore, the contribution to fit by square footage was also statistically significant for each facility group.

The linear regression models were then used to predict expected values for average quarterly job order hours for

UNWEIGHTED LEAST SQUARES LINEAR REGRESSION OF HOURS

PREDICTOR VARIABLES	COEFFICIENT	STD ERROR	STUDENT'S T	P
CONSTANT	-3.9878	1.1756	-3.39	0.0007
SF	1.4624E-03	5.4001E-05	27.08	0.0000

CASES INCLUDED	1131	MISSING CASES	0
DEGREES OF FREEDOM	1129		
OVERALL F	733.3	P VALUE	0.0000
ADJUSTED R SQUARED	0.3932		
R SQUARED	0.3938		
RESID. MEAN SQUARE	609.4		

DESCRIPTIVE STATISTICS

VARIABLE	MEAN	S.D.	N	MEDIAN	MINIMUM	MAXIMUM
HOURS	20.80	31.69	1131	8.270	0.000	250.3
PRED	20.88	19.89	1131	19.01	-2.233	104.4
RESID	-1.046E-08	24.67	1131	-1.148	-41.31	160.5

Figure 7. Results of Linear Regression for Group 3 Quarterly Moving Averages

each facility. The residuals (the deviation of actual job order hours from the expected value of job order hours) were also calculated.

Identification of HVAC Deficiencies

To identify the facilities with the most critical HVAC deficiencies, an upper limit was calculated for each group

to identify excessive job order hours. Since residuals are normally distributed with an expected value of zero, the upper limit for the residuals was calculated using the right tailed z critical value of 2.32 standard deviations of the residuals for each group. The 2.32 standard deviations equate to a confidence level of 0.01. This means that 99% of the time the hour values should be lower than this level. This high confidence level was chosen to limit the facilities identified to a number which could be reasonably investigated by a HVAC evaluation Group. The resulting upper limits for the residuals were: Group 1 - 66.7 hours/month, Group 2 - 67.8 hours/month, and Group 3 - 57.3 hours/month.

Those facilities whose positive residual value exceeded the 99% upper limit were identified as having excessive HVAC deficiencies. This procedure identified 34 of the 181 facilities in the database as having excessive job order hours for at least one of the 29 quarterly moving averages for job order hours. Those facilities which were identified and the month in which the excessive hours occurred are shown for Group 1, Group 2, and Group 3 in Appendices I, J, and K respectively. These are the facilities which have the largest potential for manhour savings if corrective actions are taken.

Graphs. The residuals for two facilities in each group were plotted to show trends in the difference between the expected average costs in three months and the actual average costs. These facilities were selected after being ranked based on the total number of months each facility had actual hours which exceeded the upper limit. The residuals were converted to dollars based on the shop rate established for the heating, refrigeration, and controls shops at Robins AFB. The resulting dollar figures for the actual residual costs as well as the upper residual cost limit were then plotted. The upper residual cost limit appears as a horizontal line in the graphs. The graphs for these facilities are shown in Figures 8 to 13 for the three facility groups.

Figure 8 shows a steady improvement in the residual costs for Building 300. However, the residuals remain close to the upper limit for excessive residual costs and the most recent data shows a trend upward. Even with the improvement, Building 300 continues to be one of the most expensive facilities on Robins AFB so far as HVAC repair costs are concerned.

Figure 9 shows that residual costs for Building 226 have been very erratic. Yet, the graph does point out two large peaks in residual costs. These peaks do not appear

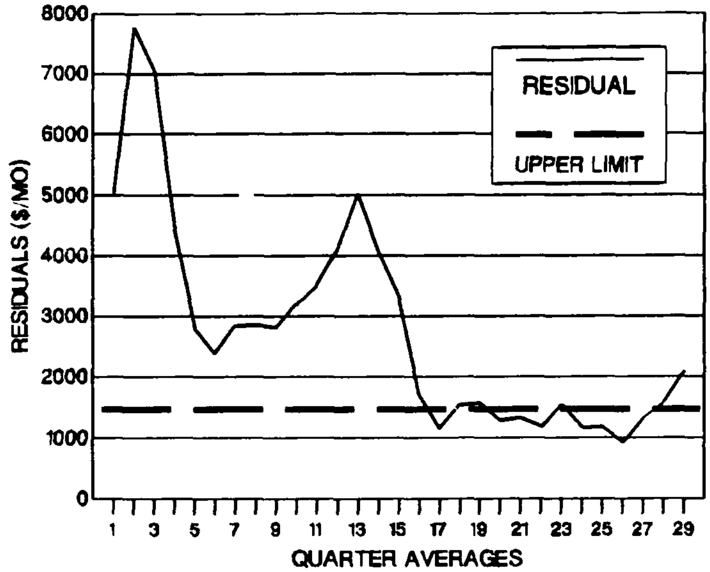


Figure 8. Building 300 Residuals. Nov 1985 - Jul 1988 (Shop Rate = $21.84/hr)

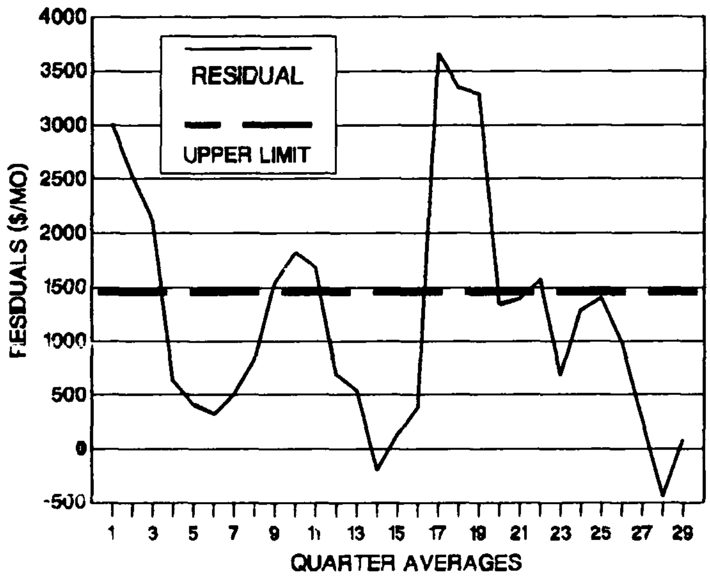


Figure 9. Building 226 Residuals. Nov 1985 - Jul 1988 (Shop Rate = $21.84/hr)

to be due to seasonal effects because they occur more than one year apart. More detailed analysis of job order data during this period might reveal a recurring problem.

Figures 10 to 13 all show a steep increase in recent residual costs. Figure 10 shows a steady increase in costs for Building 169 up to the point of the recent large increase. Building 640, shown in Figure 11, has the widest swings in residual costs. This could be due to highly concentrated repair efforts when they are undertaken. Repair efforts such as these have an adverse effect on shop scheduling.

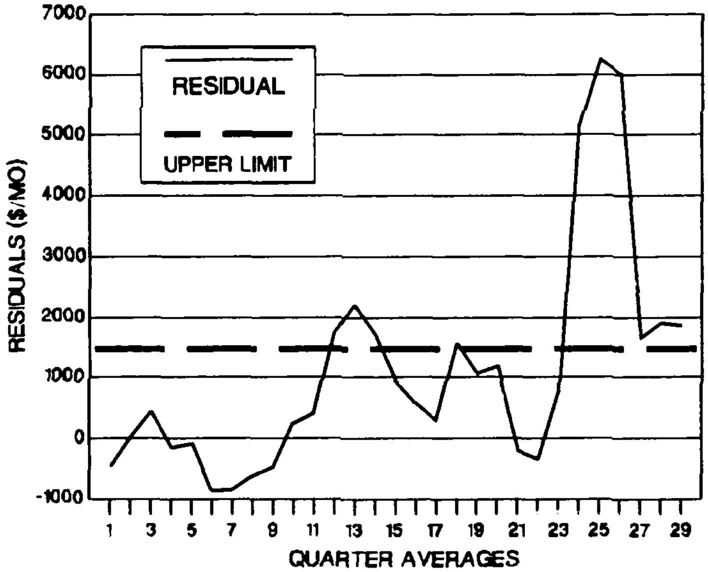


Figure 10. Building 169 Residuals. Nov 1985 - Jul 1988 (Shop Rate = $21.84/hr)

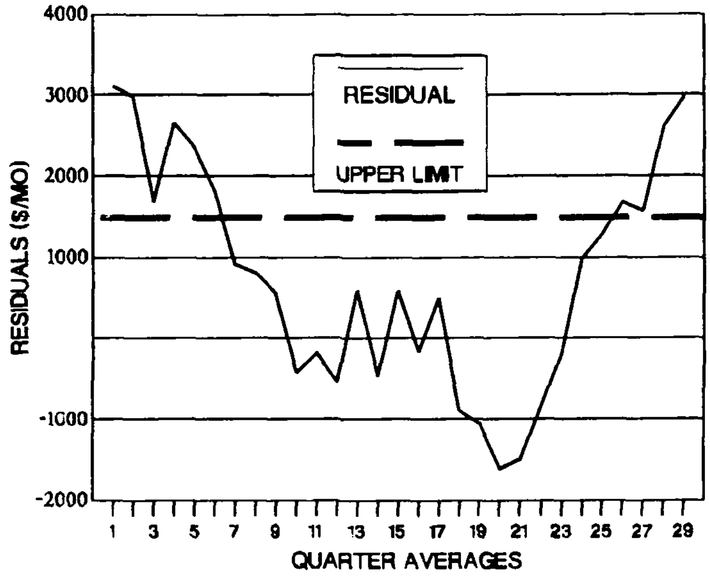


Figure 11. Building 640 Residuals. Nov 1985 - Jul 1988 (Shop Rate = $21.84/hr)

Figure 12 shows that Building 542, like Building 300, has consistently high costs even after the costs have peaked. Of the six facilities which were graphed, Building 700, shown in Figure 13, has the most balanced residual costs with the exception of the recent upward trend.

It was not surprising to find these facilities leading the list of facilities with excessive residual hours. With six years experience in design, construction, and operations at Robins AFB, the researcher has personally observed that these facilities have often suffered from chronic

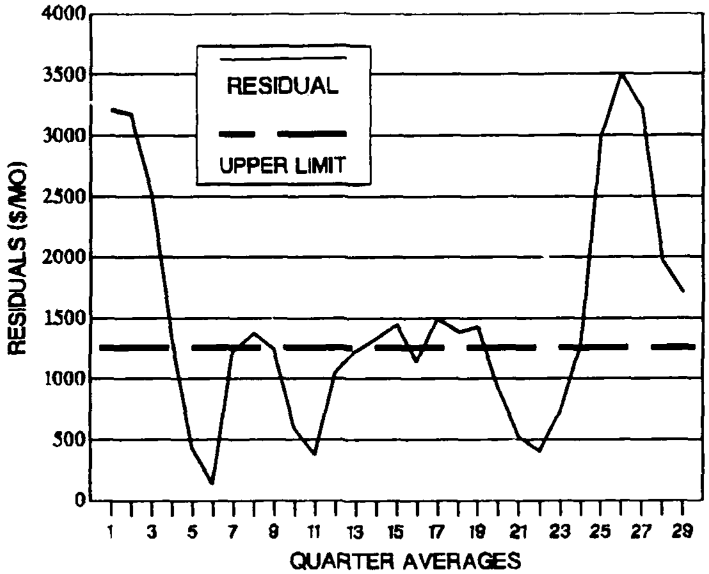


Figure 12. Building 542 Residuals. Nov 1985 - Jul 1988 (Shop Rate = $21.84/hr)

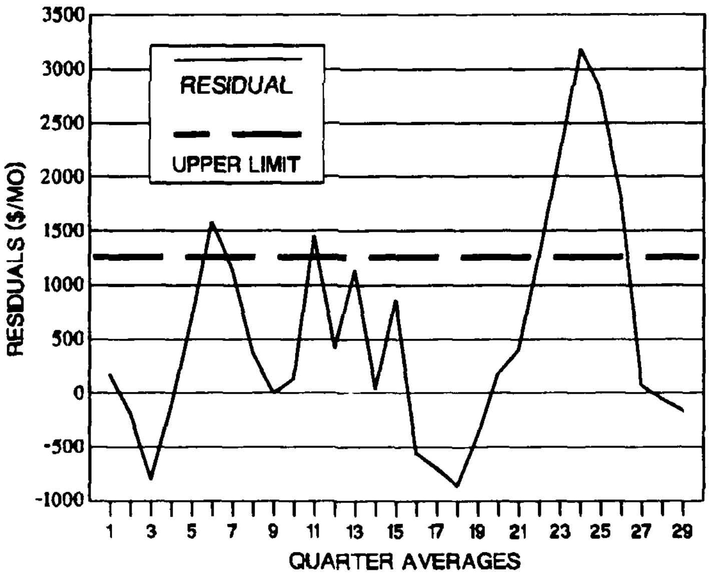


Figure 13. Building 700 Residuals. Nov 1985 - Jul 1988 (Shop Rate = $21.84)

maintenance deficiencies. This is further supported by the large number of job orders received on these facilities.

However, as stated in the introduction, verifying the underlying causes for the deficiencies in the facilities is beyond the scope of this research. This is due to the job order recording procedures used at Robins AFB. The existing system includes customer descriptions of the problem rather than the actual repairs made by the shops. Despite this fact, the objective of identifying and prioritizing facilities with the greatest potential for reducing HVAC deficiencies can be met. Reviewing recent residual costs on a monthly basis would provide insights into the underlying causes of any HVAC deficiencies because the craftsmen can still recall the cause of the problem and the repairs that were made to correct it. Monthly reviews would also allow corrective actions to be taken in a timely manner which would help prevent the large peaks in costs illustrated by these graphs. These graphs demonstrate the ability of the identification procedure to establish trends in repair costs. They also clearly show management the potential for cost savings.

Once the potential problems are identified to management, it is the responsibility of the HVAC Evaluation Group to investigate and identify specific causes for the excessive HVAC repair costs such as: poor training,

inadequate tools, poor design, inferior construction, inadequate documentation, aged equipment, inferior equipment, or insufficient maintenance. The HVAC Evaluation Group could then direct design, construction, and operations and maintenance personnel to take specific corrective actions. If recurring problems can be discovered and corrected, the HVAC shops can shift the emphasis of their fixed labor force from job order repairs to improving programming priorities, design reviews, pre-final construction inspections, training, documentation, and recurring maintenance.

Retest

The mechanical job order data collected from 15 March 1989 through 15 June 1989 showed that all six facilities identified in the initial analysis had residual hours which exceeded the upper limit. The average hours by which a facility exceeded the upper limit for this period follow:

Building 300:	109.7 hours/month
Building 226:	43.5 hours/month
Building 169:	1.3 hours/month
Building 640:	99.8 hours/month
Building 542:	65.3 hours/month
Building 700:	36.5 hours/month

The job orders completed on these six facilities represented 20.1% of all mechanical job orders completed during this three month period and 19.4% of all hours charged to

mechanical job orders during the same time. A similar calculation on the initial 33 months of data showed that the job orders completed on these six facilities during that time represented 19.9% of all mechanical job orders completed and 18.9% of all hours charged to mechanical job orders.

The HVAC Enhancement Team at Robins AFB had completed improvements on Building 640, Building 700, and Building 300 since July 1988. These improvements were primarily reconfiguration and calibration of the controls in specific areas of the three facilities. Because these improvements were made on only a small part of total facility HVAC system, they do not appear to have had much effect on the overall residual hours.

The only HVAC contract work completed on these six facilities since July 1988 was a project on Building 300. This $600,000 project replaced valves and cooling coils in approximately 1/3 of the facility. This project was not completed until June 1989 and may not have yet affected the job order hours in Building 300.

The only facility which showed some improvement was Building 169. However, the residual hours in this facility were on a downward trend prior to July 1988. The Enhancement Team had completed some improvements in this facility prior to this downward trend. The specific

improvements and their completion dates were not available. Without this information, it is not possible to credit the downward trend to the efforts of the Enhancement Team.

V. Conclusions and Recommendations

Chapter Overview

This final chapter presents a summary of the research and conclusions based on the results. Recommendations for further study are also presented.

Project Summary

The objective of this research was to develop a procedure for the Robins AFB, GA, HVAC Evaluation Group which could systematically and objectively identify facilities with HVAC deficiencies and prioritize them by the potential for cost savings. The literature review provided the framework for the methodology used in this research. WIMS HVAC job order data from Robins AFB was analyzed for a thirty-three month period. The results of this analysis were presented in Chapter IV.

Conclusions

Analysis of job order data provided an appropriate method for use by the Robins AFB HVAC Evaluation Group to identify and prioritize HVAC deficiencies. Job order data was tangible evidence of the repair workload and it was

readily available from the WIMS. Job order analysis also provided an indication of the capability of the HVAC system to perform its job.

Of the variables available in the job order database, job order hours proved to be most easily obtained measurement. Job order hours could also be directly converted to dollar figures using the appropriate shop rates. This satisfied the goal of presenting information to management in terms of dollars. However, ranking facilities based on job order hours alone produced a listing where only the largest facilities were identified as having HVAC deficiencies. If the facilities were ranked by hours/square foot, the resulting list identified only the smallest facilities where even a few job order hours resulted in a large hour/square foot ratio. Therefore, it was necessary to define a level of excessive job order hours to indicate that an HVAC deficiency existed. To determine what constituted excessive job order hours, linear regression was used to predict the expected job order hours. The difference between the expected and actual hours was then compared to an upper limit which was established statistically.

Because job orders in the WIMS were recorded by facility, comparisons of HVAC job order hours for the purpose of prioritizing deficiencies were made on a facility

basis. This made it necessary to evaluate the effect of facility age, square footage, and type on the ability to predict expected job order hours.

Based on correlations and frequency histograms, it was determined that facility age did not have a significant effect on job order hours. Therefore, age could not be used to indicate facilities with significant HVAC deficiencies. Facility square footage was found to have a significant linear relationship with job order hours. This allowed liner regression to be used as a means of predicting the expected job order hours for a facility. Facility type was found to affect the strength of the linear relationship between facility square footage and job order hours. Major facility classifications, based on the Real Property Category Codes, were used to group facilities so the linear relationship between square footage and hours was strengthened, thereby increasing the ability of square footage to predict job order hours.

Expected facility job order hours were computed using the linear regression models obtained with facility square footage as a predictor of hours. The difference between the expected facility hours and the actual facility hours (residuals) was used to prioritize HVAC deficiencies based on the potential for reducing job order hours and, thus, the potential for cost savings.

Statistical methods were used to establish an upper limit for the residual costs within each facility group. This upper limit was chosen to restrict the facilities identified to a number which the Robins AFB HVAC Evaluation Group could reasonably expect to investigate. Those facilities whose positive residual value exceeded the upper limit in any given month were identified as having excessive HVAC job order hours and therefore excessive deficiencies for that particular month. Because residuals represented the potential for improvement, ranking facilities within groups based on residual hours provided a prioritized listing of facilities with the largest potential for savings.

Graphs of the residuals showed how they could be used to evaluate trends in job order hours and study the effect of corrective actions. The possible causes for the excessive residual hours shown by the graphs could not be verified due to the job order recording procedures used at Robins AFB. Customer descriptions of the problem were recorded rather than the actual repairs made by the shops. Despite this fact, graphing recent residual costs on a monthly basis would provide insights into the underlying causes of any HVAC deficiencies because the craftsmen can still recall the cause of the problem and the repairs that were made to correct it. Monthly reviews would also allow

corrective actions to be taken in a timely manner which would help prevent the large peaks in costs illustrated by the graphs.

Recommendations for Further Study

This study could be generalized AIr Force wide if another researcher would determine if additional facility groups would provide a more accurate prediction of repair costs. Additional groups might provide a stronger correlation between facility square footage and job order hours within the groups. These facility groupings should then be tested at several bases to determine if the base mission and location affect the facility groupings.

Improved WIMS procedures for recording job order data could provide an indication of the causes for HVAC deficiencies. I would suggest that another researcher survey service organizations to determine the operation and maintenance productivity measures currently in use. The researcher should also determine which features would be beneficial if incorporated into the Civil Engineering WIMS. I would recommend contacting the Association of Physical Plant Administrators for Colleges and Universities to suggest the possibility of surveying their membership. College and University facility operations closely parallel those of Air Force Civil Engineering.

Appendix A: List of Abbreviations

AFB - Air Force Base
AFESC - Air Force Engineering and Services Center
AFIT - Air Force Institute of Technology
AFLC - Air Force Logistics Command
AFM - Air Force Manual
AFR - Air Force Regulation
ANOVA - Analysis of Variance
APPA - Association of Physical Plant Administrators
ASHRAE - American Society of Heating, Refrigerating, and Air Conditioning Engineers
BCE - Base Civil Engineering
BLDG - Building
BLDGRP - Building Group
CADD - Computer Aided Drafting and Design
CE - Civil Engineering
COMPYRMO - Year and Month Completed
CURSHOP - Current Shop
CWON - Collection Work Order Number
DEM - Civil Engineering Operations Branch
DEMM - Civil Engineering Mechanical Section
DF - Degrees of Freedom
EQAH - Expected Quarterly Average Hours
FAC - Facility
FIMA - Facilities Infrastructure Management Aid
HR - Hour
HRAGE - Hour/Facility Age
HRJO - Hour/Job Order
HRPJO - Hour/Job Order
HRSF - Hour/Facility Square Feet
HVAC - Heating, Ventilating, and Air Conditioning
JO - Job Order
JOAGE - Job Order/Facility Age
JOSF - Job Order/Facility Square Feet
LSD - Least Significant Difference
MEMET - Mechanical Equipment Maintenance Evaluation Team
MSE - Mean Square Error
OQ - Officer/Cadet Quarters
PRED - Predicted Value
RESID - Residual Value
RIT - Rochester Institute of Technology
SAC - Strategic Air Command
SAS - Statistical Analysis System
SF - Square Feet
SQ - Square
SS - Sum of Squares
STD - Standard
VMS - Virtual Memory System
WIMS - Work Information Management System

Appendix B: WIMS Procedures

The procedures described in this appendix are very detailed. These details are included to demonstrate the difficulties and limitations of the WIMS while attempting to manipulate the data collected from Robins AFB. A COBOL program was eventually required to overcome these problems.

Data Collection

Four MJOB data files were obtained from Robins AFB. MJOB is the file name used at Robins for their job order data files. These data files were then combined into two files using the WIMS Create utility to eliminate duplicate data entries. Because the original data files did not use the same control file, the two remaining data files could not be combined at this point.

Data Reduction

A new field called "compyrmo" was defined, using the year and month of the job order completion date, to allow subtotals of job order hours by facility for each month in the database. Two steps had to be used to reduce the cases and fields of the database to the relevant data. This was necessary because the Inquiry utility would not eliminate fields when the results were extracted to a file rather than the screen and the Create utility could not be used to

eliminate cases. The Create utility was used to define new data files, which reduced the fields in the database to the facility number, job order number, year and month completion date, and total hours. The Inquiry utility was used to reduce the cases to those job orders that had a Do-It-Now (DIN) truck number or shop cost center code used by the heating, refrigeration or controls shops.

The internal field length for any variable must be defined with the same number of characters in both the data file and the control file to use the WIMS utilities. A mismatch of the internal length between the data and control files for the field CURSHOP had to be corrected before the Inquiry would function. This problem was the result of an error in the original file characteristics provided by the Engineering and Services Center. The problem caused by this mismatch is not limited to this research. It would cause a problem for anyone using the Inquiry utility in conjunction with the MJOB control file provided by the Engineering and Services Center.

After the fields and cases were reduced, the internal length for total hours was modified by writing a new control file and the two data files were combined into a single database to eliminate duplicate data entries.

Data Summaries

Reports. From this data file the Report utility was used to give monthly subtotals of job order total hours by facility and sort the database, first by facility then by completion date. The report was also used to create a new field called "count". This field was the total number of job orders completed in a facility each month. The results of the report contained the individual job order records for facility

number, year and month completed, total hours, and count as well as the subtotals for monthly total hours and job order count.

Problems. The first problem encountered in obtaining data summaries was the need for a data file with subtotals only. To eliminate individual records from the report and print only the subtotals, the "sum only" print option was selected. This is the only group option available on both the report menu and the print menu. The data field sizes had to be increased to use the sum option because facility and year/month completed were also subtotaled when the report was printed. If these fields were changed to characters to prevent them from being subtotaled, the sum only option would not print them out on the report. The minimum, maximum, and average report summary options could

not be used to correct this problem because they would not print out on the report when the sum only option was used.

A second problem involved obtaining a useful data file from the report utility. WIMS will not print report results directly to a data file. The results can be saved as a print file rather than sending them to the printer. To use this file as a data file, would have required removing the print file characteristics as well as page headers and column headings and delimiting the data records with commas for use in a spreadsheet.

Solution. Rather than try to correct these problems, Mark Klosterman from the Engineering and Services Center wrote a COBOL program (see Appendix B) which extracted the relevant data from the Robins AFB data files and created a new data file in the required format. This program produced a comma delimited data file with the facility number, completion date, total hours, and job order count. The program also sorted by facility with a secondary sort on the completion date.

Appendix C: COBOL Program for WIMS Data Retrieval

```
*-----------------------------------------------------------
IDENTIFICATION DIVISION.
*-----------------------------------------------------------

PROGRAM-ID. MJOBCRE.

*-----------------------------------------------------------
ENVIRONMENT DIVISION.
*-----------------------------------------------------------

INPUT-OUTPUT SECTION.
FILE-CONTROL.
    SELECT INPUT1 ASSIGN TO "INPUT1" NODISPLAY
         ORGANIZATION IS INDEXED,
         RECORD KEY IS JUNK-KEY
         ACCESS IS DYNAMIC.
    SELECT JUNK ASSIGN TO "JUNK" NODISPLAY
         ORGANIZATION IS INDEXED,
         RECORD KEY IS JUNK-KEY
         ACCESS IS DYNAMIC.
*-----------------------------------------------------------
DATA DIVISION.
*-----------------------------------------------------------

FILE SECTION.
FD  INPUT1
         RECORD CONTAINS 36 CHARACTERS
         LABEL RECORDS ARE STANDARD
         VALUE OF FILE NAME IS "MJOBC2",
                  LIBRARY    IS "MJOBDATA",
                  VOLUME     IS "WRK001".
01  INPUT1-RECORD.
    03  INPUT1-JO            PIC X(05).
    03  INPUT1-FAC           PIC X(05).
    03  INPUT1-YRMD          PIC X(04).
    03  INPUT1-HRS           PIC S9(03)V9 SIGN TRAILING.

FD  JUNK
         RECORD CONTAINS 23 COMPRESSED CHARACTERS
         LABEL RECORDS ARE STANDARD
         VALUE OF FILE NAME IS "MJOBTOT"
                  LIBRARY    IS "MJOBDATA"
                  VOLUME     IS "WRKOO1".
01  JUNK-RECORD.
    03   JUNK-KEY.
         05   JUNK-FAC                 PIC X(05).
         05   JUNK-COMMA1              PIC X    .
         05   JUNK-YRMD                PIC X(04).
```

```
                    05 COMMA2                            PIC X     .
          03    JUNK-HRS                                 PIC 9(05)V9.
          03    JUNK-COMMA3                              PIC X     .
          03    JUNK-COUNT                               PIC 9(04).
          03    JUNK-COMMA4                              PIC X     .
      *-----------------------------------------------------------
      WORKING-STORAGE SECTION.
      *-----------------------------------------------------------
      01   EXTRACT-INFORMATION.
           03   EXTRACT-IPL-VOL      PIC XX        VALUE "XV".
           03   INPL-VOLUME          PIC X(06)     VALUE SPACES.
           03   EXTRACT-ID           PIC XX        VALUE "ID".
           03   USER-ID              PIC XXX       VALUE SPACES.
           03   EXTRACT-NAME         PIC XX        VALUE "NA".
           03   USER-NAME            PIC X(24)     VALUE SPACES.

      *-----------------------------------------------------------
      PROCEDURE DIVISION.
      *-----------------------------------------------------------

      10-START-PROGRAM.
           OPEN OUTPUT HUNK CLOSE JUNK.
           OPEN SHARED INPUT1 JUNK.
           MOVE SPACES TO INPUT1-RECORD.
           START INPUT1 KEY NOT < INPUT1-JO.
      100-READ.
           READ INPUT1 NEXT AT END
                CLOSE INPUT1 JUNK
                STOP RUN.
           MOVE INPUT1-FAC TO JUNK-FAC.
           MOVE INPUT1-YRMO TO JUNK-YRMO.
           MOVE ","          TO JUNK-COMMA1 JUNK-COMMA2.
           READ JUNK HOLD INVALID KEY
                PERFORM 100-WRITE
                GO TO 100-READ
           COMPUTE JUNK-HRS = (INPUT1-HRS * 1) + JUNK-HRS.
           ADD 1 TO JUNK-COUNT.
           REWRITE JUNK-=RECORD.
           GO TO 100-READ.

      100-WRITE.
           MOVE SPACES TO JUNK-RECORD.
           MOVE ZERO   TO JUNK-COUNT JUNK-HRS.
           MOVE INPUT 1-FAC TO JUNK-FAC.
           MOVE INPUT1-YRMD TO JUNK-YRMD.
           MOVE ","    TO JUNK-COMMA1 JUNK-COMMA2 JUNK-COMMA3
                          JUNK-COMMA4.
           COMPUTE JUNK-HRS = (INPUT1-HRS * 1) + JUNK-HRS.
           MOVE 1 TO JUNK-COUNT.
           WRITE JUNK-RECORD.
```

Appendix D: BASIC Program for Data File Transformations

```
10 DIM YRMO(33),BLDG(352),HR(352,33),JO(352,33)
20 FOR I=1 TO 352
30 FOR J=1 TO 33
40 HR(I,J)=0:JO(I,J)=0
50 NEXT J
60 NEXT I
70 FOR J=1 TO 33
80 READ YRMO(J)
90 NEXT J
100 OPEN "I",#1,"c:\mjob.dat"
110 I=0
120 LASTBLDG=0
130 INPUT#1,BLDG,YRMO,HR,JO
140 IF BLDG<0 GOTO 250
150 IF BLDG=LASTBLDG GOTO 190
160 I=I+1
170 BLDG(I)=BLDG
180 LASTBLDG=BLDG
190 FOR J=1 TO 33
200 IF YRMO<>YRMO(J) GOTO 230
210 HR(I,J)=HR
220 JO(I,J)=JO
230 NEXT J
240 GOTO 130
250 CLOSE#1
260 OPEN "O",#2,"c:\hrsjos.dat"
270 PRINT#2,-999;",";
280 FOR J=1 TO 33
290 PRINT#2,YRMO(J);",";
300 NEXT J
310 PRINT#2,CHR(13);
320 FOR I=1 TO 352
330 PRINT#2,BLDG(I);",";
340 FOR J=1 TO 33
350 PRINT#2,HR(I,J);",";JO(I,J);",";
360 NEXT J
370 PRINT#2,CHR$(13);
380 NEXT I
390 CLOSE #2
400 PRINT CHR$(7)
410 END
420 DATA 8511,8512,8601,8602,8603,8604,8605,8606,
    8607,8608,8609,8610
430 DATA 8611,8612,8701,8702,8703,8704,8705,8706,
    8707,8708,8709,8710
440 DATA 8711,8712,8801,8802,8803,8804,8805,8806,8807
```

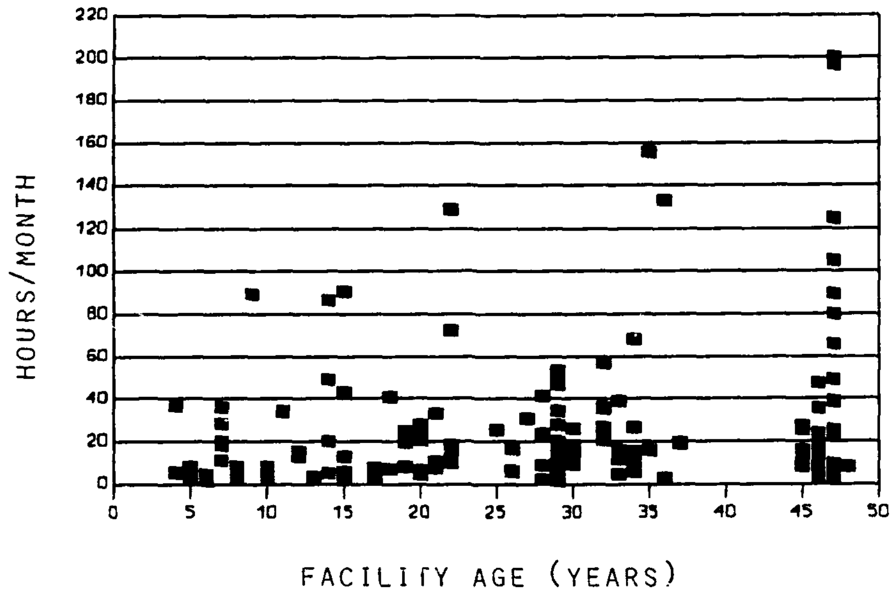
Appendix E: <u>BASIC Program for Computing Quarterly Moving Averages</u>

```
10 DIM DAT(31)
20 OPEN "I",#2,"c:\data\hrs.dat"
30 OPEN "O",#1,"c:\data\mahrs.dat"
40 FOR K=1 TO 352
50 INPUT#2,BLDG$,AGE,SIZE,TYPE
60 PRINT#1,BLDG$;",";AGE;",";SIZE;",";TYPE;
70 FL=0
80 FOR J=1 TO 31
90 INPUT#2,DAT(J)
100 IF FL=1 THEN FL=0:GOTO 120
110 IF J=6 OR J=10 THEN FL=1:GOTO 90
120 NEXT J
130 INPUT#2,X
140 FOR I=3 TO 31
150 PRINT#1,",";((DAT(I)+DAT(I-1)+DAT(I-2))/3);
160 NEXT I
170 PRINT#1,CHR$(13);CHR$(10);
180 NEXT K
190 CLOSE #1
200 CLOSE #2
210 PRINT CHR$(7)
220 END
```

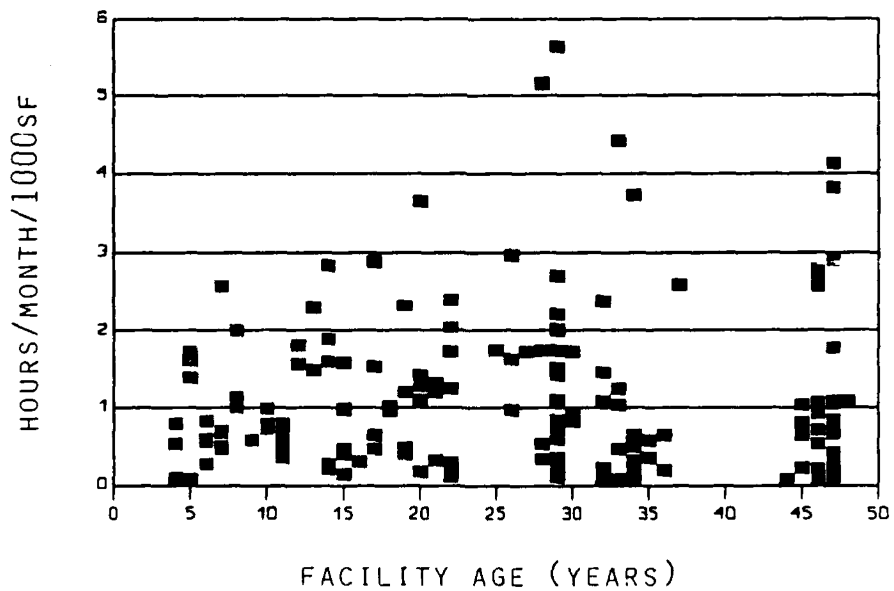
Appendix F: SAS Program for ANOVA and Comparison of Means

```
options linesize=78;
data=ratio;
infile iiigrp obs=181;
input hrpjo bldgrp;
proc anova;
class bldgrp;
model hrpjo=bldgrp;
means bldgrp / lsd tukey snk duncan waller scheffe lines;
means bldgrp / lsd tukey scheffe cldiff;
```

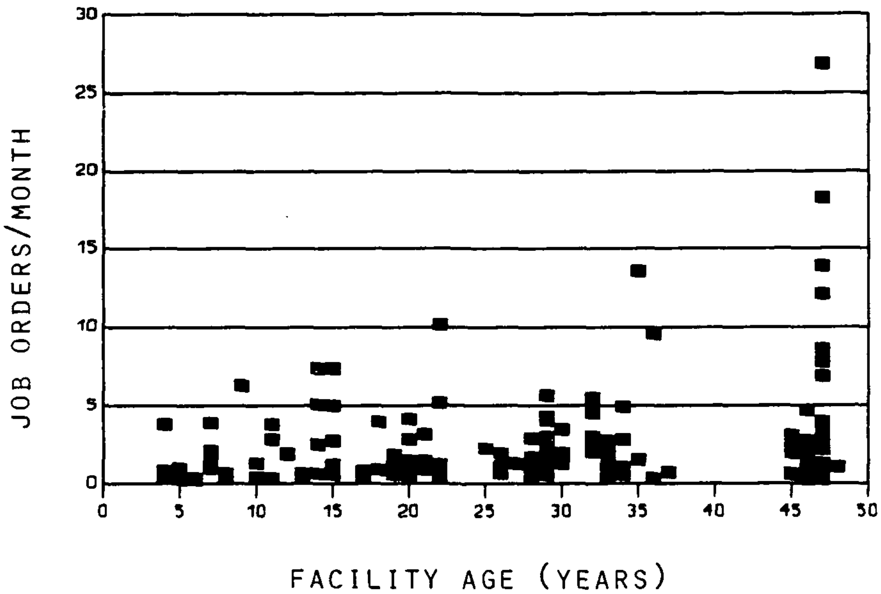
Appendix G: Scatterplots



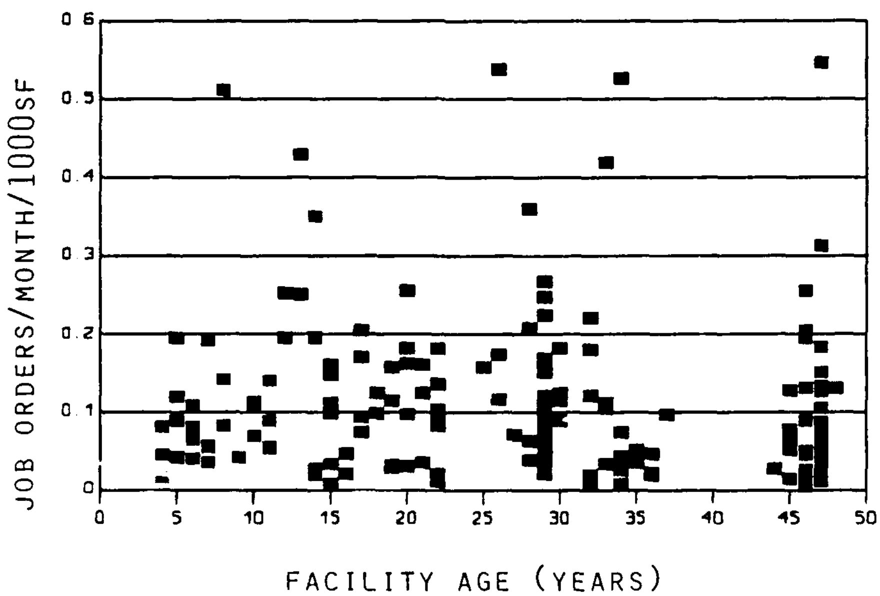
Scatterplot of Facility Age versus Hours/Month



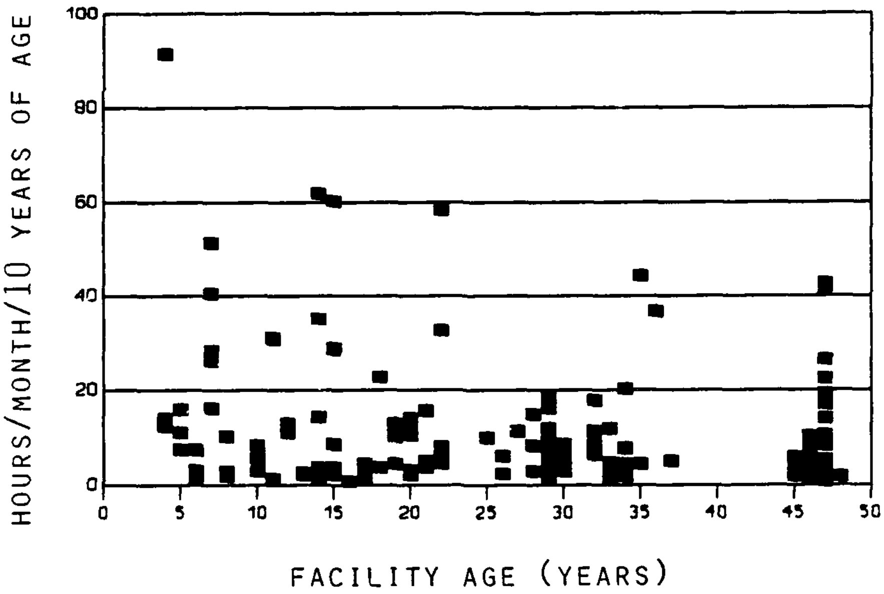
Scatterplot of Facility Age versus Hours/Month/1000SF



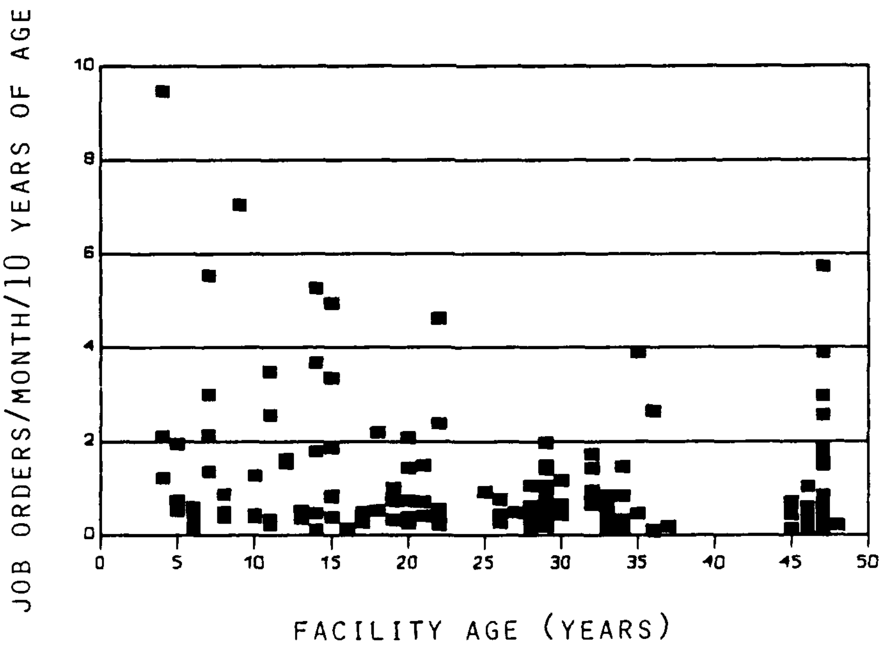
Scatterplot of Facility Age versus Job Orders/Month



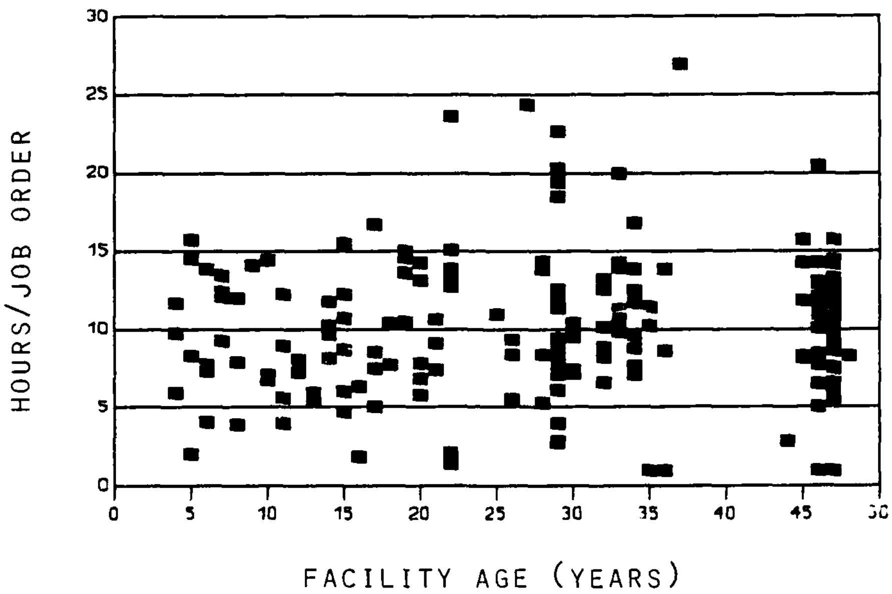
Scatterplot of Facility Age versus
Job Orders/Month/1000SF.



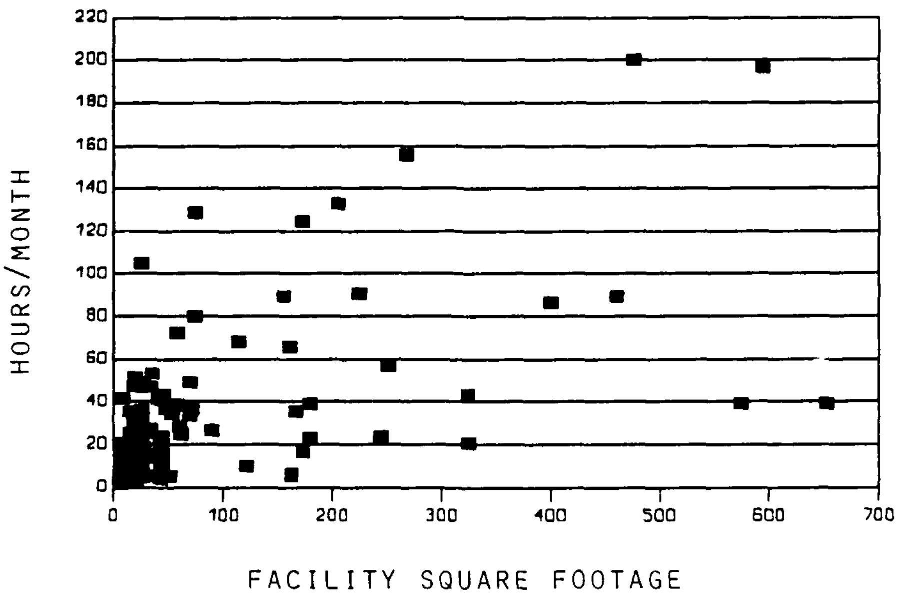
Scatterplot of Facility Age versus
Hours/Month/10 Years of Age



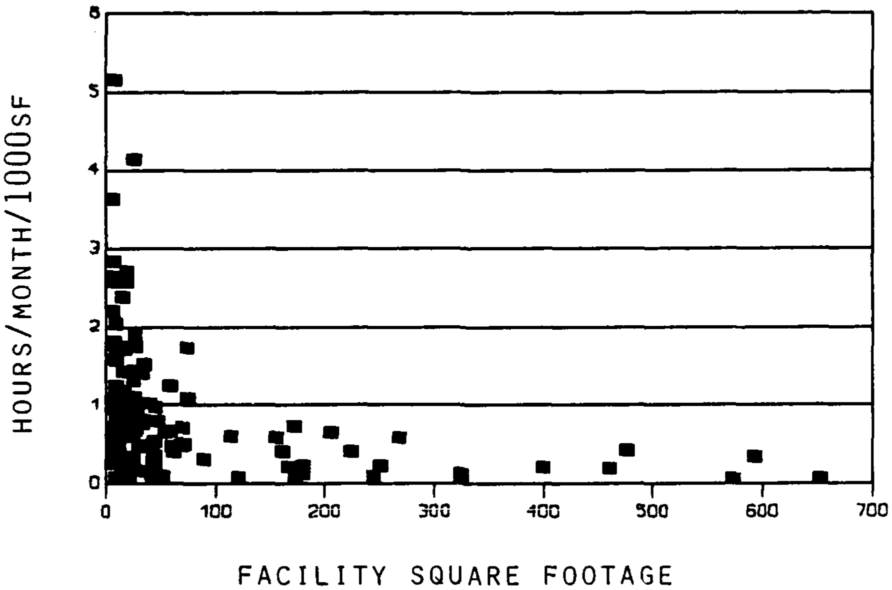
Scatterplot of Facility Age versus
Job Orders/Month/10 Years of Age



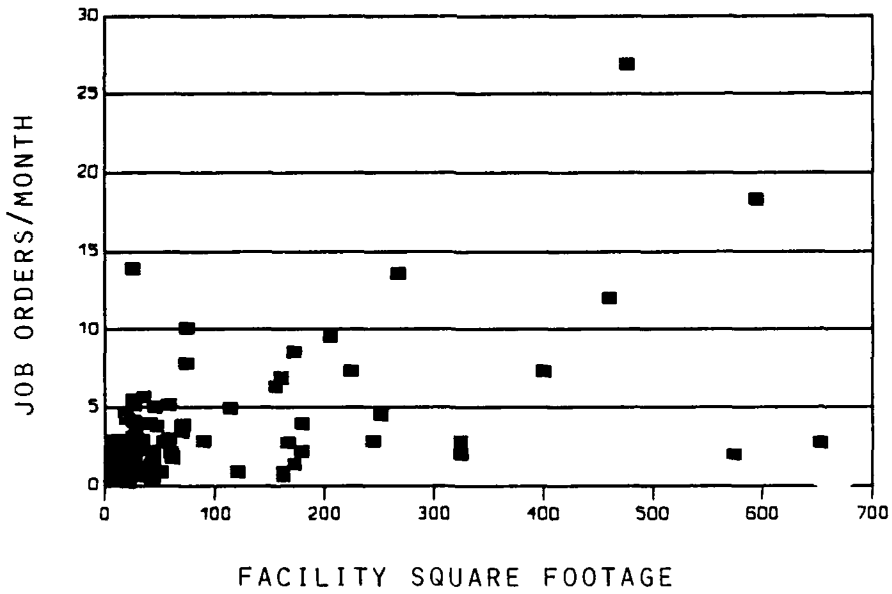
Scatterplot of Facility Age versus Hours/Job Order



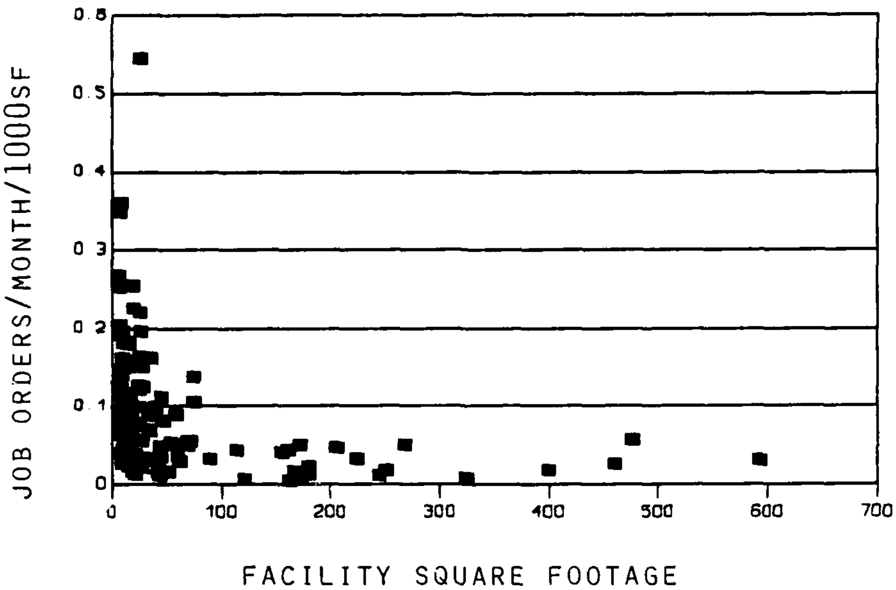
Scatterplot of Facility Square Footage versus Hours/Month



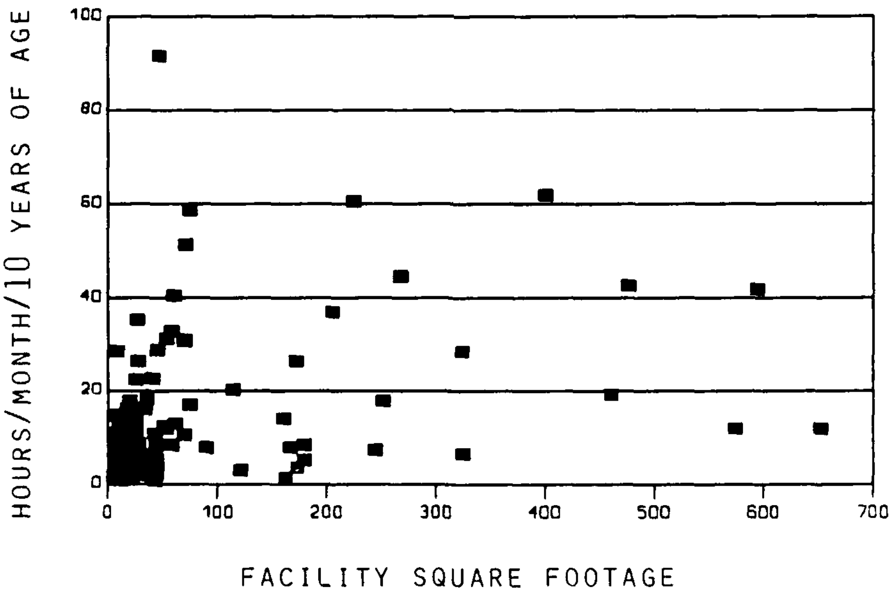
Scatterplot of Facility Square Footage versus Hours/Month/1000SF



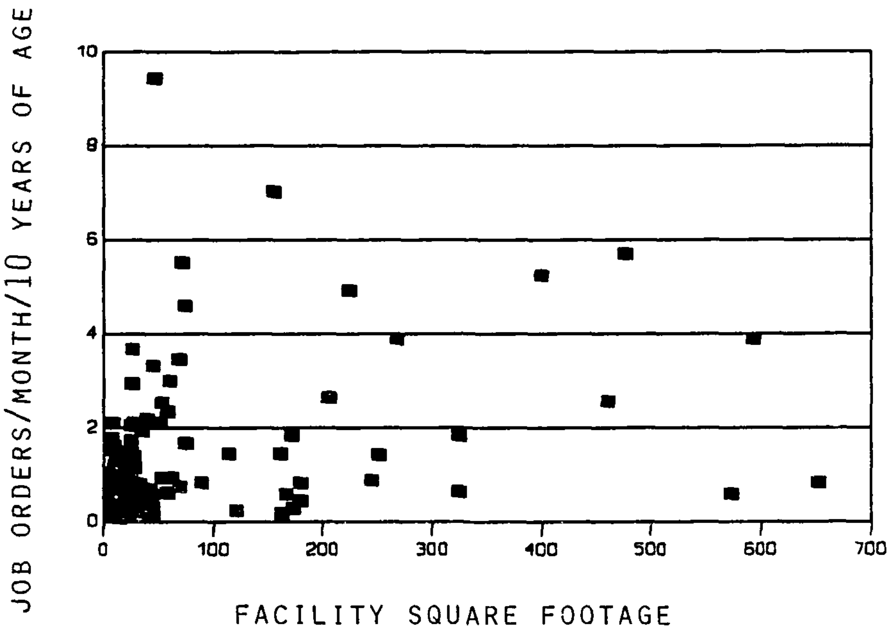
Scatterplot of Facility Square Footage versus Job Orders/Month



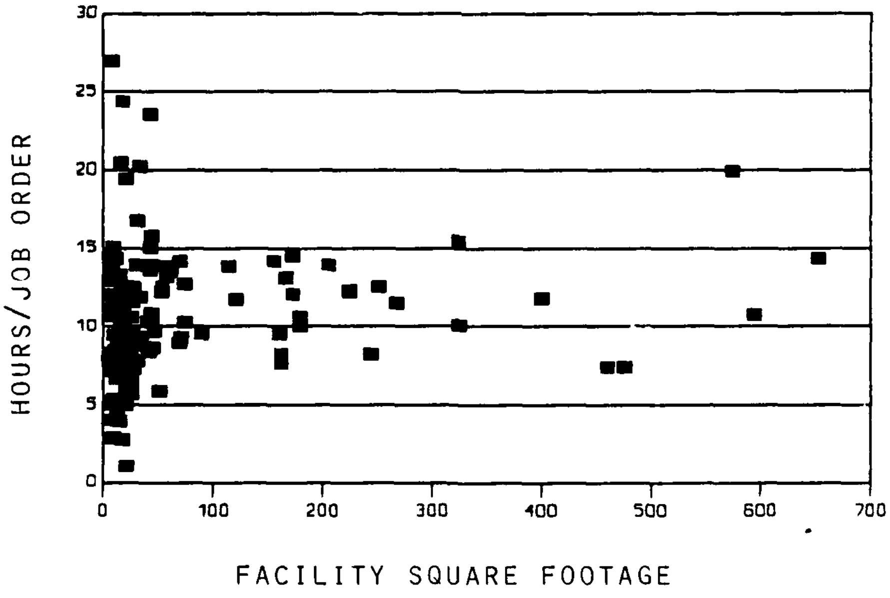
Scatterplot of Facility Square Footage versus Job Orders/Month/1000SF



Scatterplot of Facility Square Footage versus Hours/Month/10 Years of Age

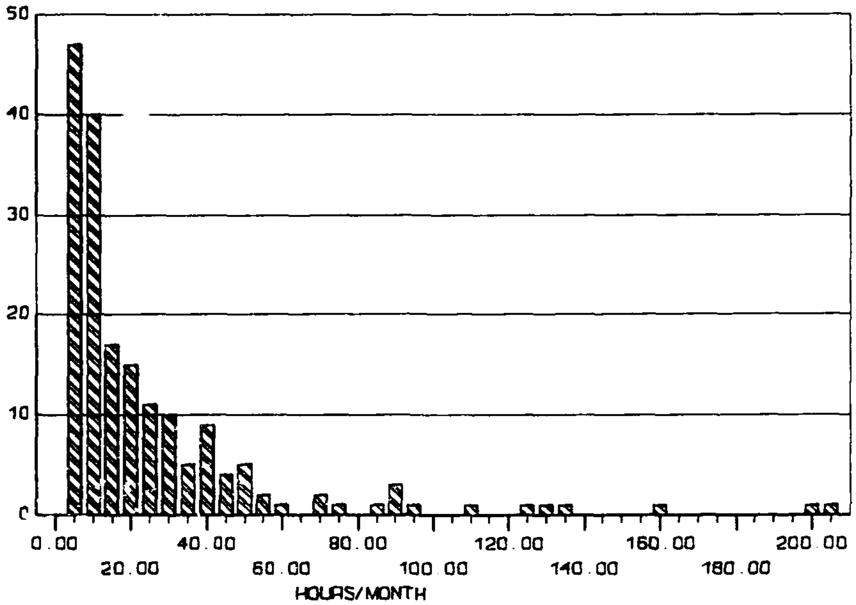


Scatterplot of Facility Square Footage versus Job Orders/Month/10 Years of Age

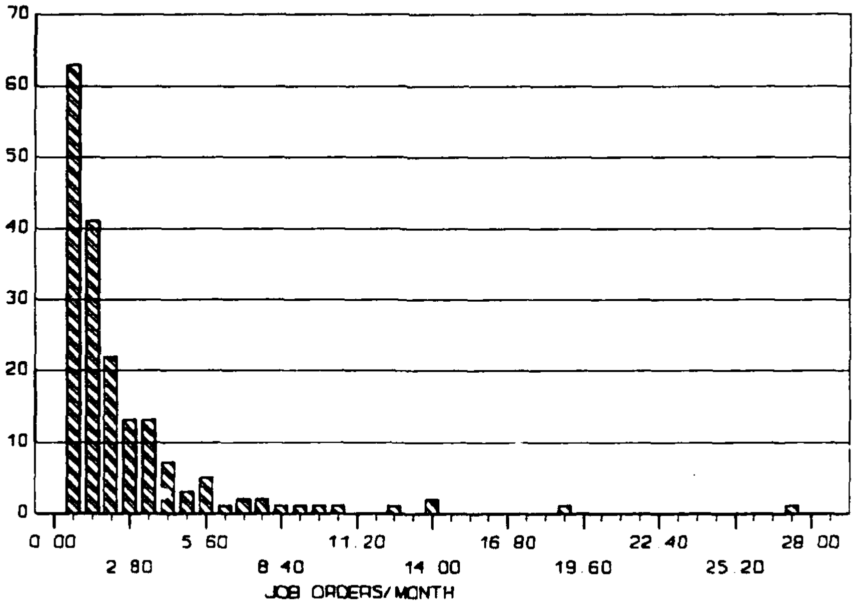


Scatterplot of Facility Square Footage versus Hours/Job Order

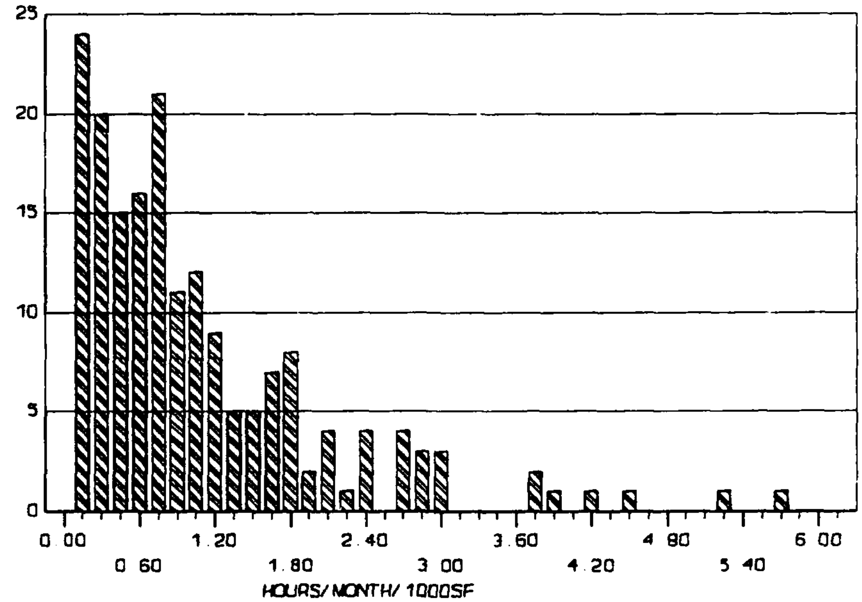
Appendix H: Frequency Histograms



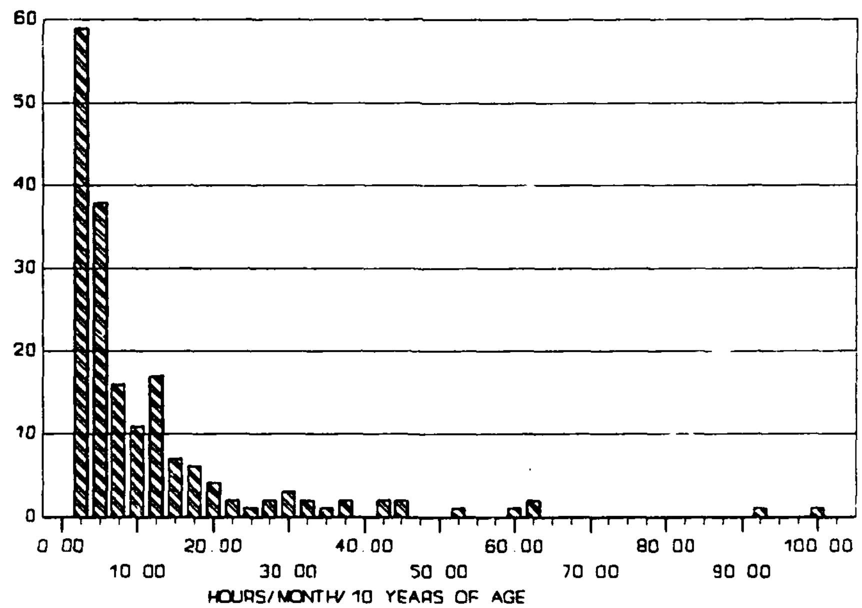
Frequency Histogram of Average Hours/Month



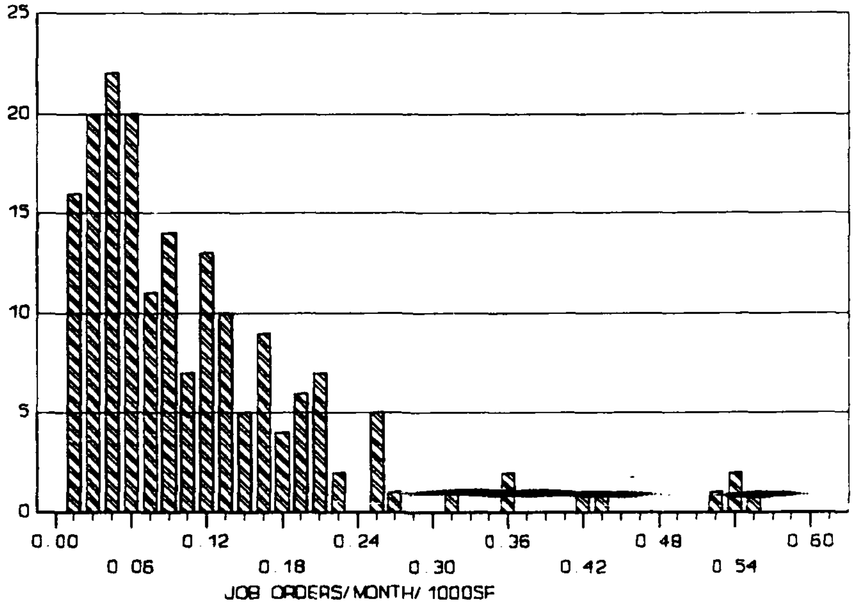
Frequency Histogram of Average Job Orders/Month



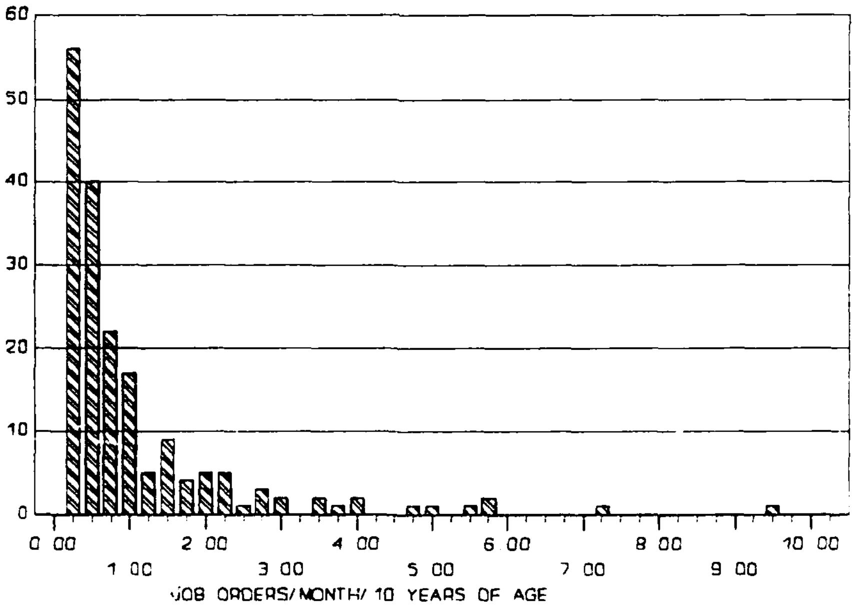
Frequency Histogram of Hours/Month/1000 Square Feet



Frequency Histogram of Hours/Month/10 Years of Age



Frequency Histogram of Job Orders/Month/1000 Square Feet



Frequency Histogram of Job Orders/Month/10 Years of Age

Appendix I: GROUP 1 - Facilities Exceeding the Upper Limit For Residuals (hours/month)*

FACILITY	B9	B12	B78	B127	B210
SQ FEET	7727	19057	35039	69142	113598
QUARTER					
1	-8.09	74.52	51.57	34.98	16.34
2	-11.43	80.35	44.07	31.65	44.84
3	-8.09	40.02	49.04	2.98	61.84
4	4.57	-2.62	33.70	-16.02	72.84
5	9.41	16.38	40.44	-6.35	31.34
6	15.41	15.88	47.47	7.32	47.47
7	2.74	16.72	57.60	10.48	41.64
8	-2.09	12.55	33.04	0.48	39.97
9	-10.76	14.02	13.70	9.82	10.51
10	-9.43	16.35	1.10	7.65	17.34
11	-8.43	6.02	21.44	16.32	40.34
12	-9.43	19.72	26.10	-7.35	39.51
13	-10.76	18.05	58.07	-3.35	45.67
14	-11.76	32.72	31.07	-5.02	41.67
15	-2.66	29.88	47.90	9.48	56.01
16	-0.99	31.72	29.40	11.65	59.17
17	22.01	11.05	50.90	8.32	101.51
18	13.91	-5.12	61.74	-7.85	98.67
19	112.91	-3.78	42.74	-3.35	90.34
20	96.07	-6.78	26.24	20.65	9.67
21	101.07	23.55	-0.93	21.98	20.67
22	1.91	80.22	26.57	27.98	22.57
23	8.07	121.05	29.57	3.65	35.24
24	2.74	95.05	44.90	9.98	15.24
25	1.24	35.88	66.74	-7.02	11.34
26	-6.76	24.22	66.90	3.32	19.67
27	-5.76	40.22	68.07	-5.35	34.67
28	-5.76	116.22	21.67	80.65	61.34
29	-10.09	102.38	17.17	73.98	48.34

* residuals which exceed the upper limit are underlined

GROUP 1 - Facilities Exceeding the
Upper Limit For Residuals (hours/month)*

FACILITY	B220	B226	B227	B272	B300
SQ FEET	58082	155042	60015	18440	475992
QUARTER					
1	-5.53	137.60	-3.96	44.47	230.62
2	7.14	115.77	-11.79	61.63	355.29
3	26.80	97.10	27.54	66.13	322.12
4	31.14	28.94	56.88	45.47	202.62
5	18.14	18.87	71.78	23.97	127.29
6	3.10	14.87	33.44	25.97	108.89
7	6.44	23.20	8.44	57.97	129.99
8	25.77	37.54	-6.12	89.13	130.65
9	24.47	70.47	22.54	76.97	128.55
10	22.80	83.14	11.88	36.63	146.49
11	9.14	76.70	11.54	5.13	160.82
12	9.64	31.44	-17.46	9.80	187.49
13	4.64	24.60	-15.79	18.13	230.29
14	-6.53	-9.06	-14.12	21.47	186.29
15	-9.03	6.27	-2.79	53.47	152.45
16	-0.03	17.77	-5.12	48.80	78.05
17	28.14	167.77	1.54	47.97	52.55
18	29.44	153.10	-9.12	11.63	70.55
19	51.44	150.44	-1.79	16.30	72.29
20	36.44	61.44	0.88	30.47	58.62
21	43.14	64.10	7.54	34.47	60.89
22	19.80	72.20	0.21	34.80	53.72
23	6.47	31.20	-1.12	18.80	70.39
24	31.60	59.20	41.88	18.30	53.12
25	60.60	64.20	47.88	9.30	53.45
26	70.27	45.20	38.54	10.30	42.29
27	31.47	12.54	5.54	14.63	60.12
28	-5.53	-20.23	-0.12	22.30	72.42
29	13.14	3.94	5.54	35.80	95.39

* residuals which exceed the upper limit are underlined

GROUP 1 - Facilities Exceeding the Upper Limit For Residuals (hours/month)*

FACILITY	B301	B376	B660	B905
SQ FEET	460277	400000	250724	71000
QUARTER				
1	30.90	-22.66	56.57	8.73
2	52.90	1.84	50.74	19.40
3	<u>90.90</u>	15.17	<u>72.74</u>	25.90
4	<u>84.33</u>	11.90	29.24	21.57
5	26.73	3.40	35.41	11.90
6	-14.40	20.24	-13.40	-18.43
7	-17.27	58.67	5.27	-18.27
8	4.53	<u>67.67</u>	3.27	11.73
9	-13.50	38.84	1.40	13.97
10	-0.90	2.00	47.24	13.63
11	-7.27	-11.16	53.41	-1.70
12	62.57	-22.83	<u>77.24</u>	6.73
13	64.07	-32.33	27.41	12.07
14	<u>95.90</u>	-38.16	19.24	1.90
15	39.73	16.50	-12.26	8.73
16	36.87	56.67	-7.99	3.73
17	-7.80	64.84	-11.33	22.57
18	-4.03	41.50	31.34	6.07
19	-6.50	16.67	27.74	14.40
20	-3.33	48.67	24.41	-10.27
21	-9.27	53.84	-13.26	-4.03
22	7.23	66.34	-11.93	-0.37
23	30.23	27.67	-2.76	15.63
24	40.23	-2.50	-6.76	13.40
25	31.57	-11.90	-24.26	28.57
26	-6.77	3.60	-33.43	16.30
27	-12.00	0.94	-26.76	17.30
28	-38.17	28.57	-28.93	-8.20
29	-39.17	<u>70.40</u>	-4.43	<u>80.40</u>

* residuals which exceed the upper limit are underlined

Appendix J: GROUP 2 - Facilities Exceeding the Upper Limit For Residuals (hours/month)*

FACILITY	B47	B52	B76	B89	B110
SQ FEET	42630	17750	33238	57890	160668
QUARTER					
1	-24.63	53.52	31.08	98.85	16.97
2	-17.79	26.85	45.08	71.68	18.14
3	2.87	11.19	58.41	63.68	20.30
4	2.87	-14.81	17.41	48.52	-4.70
5	-3.96	-14.81	9.44	89.35	-0.03
6	-24.36	-14.81	-10.96	69.95	-27.43
7	-24.36	-14.81	-5.96	91.62	-0.26
8	-24.36	-11.48	-8.66	37.28	41.57
9	-24.29	-4.81	-1.26	31.68	71.14
10	-21.13	-2.65	2.58	23.35	75.30
11	-4.96	40.69	24.91	11.52	7.30
12	-5.29	67.35	22.58	10.18	-20.86
13	1.71	72.35	30.08	-2.82	-54.63
14	-5.46	33.69	20.08	4.85	-33.96
15	5.54	7.19	29.74	24.18	-10.13
16	-3.29	6.02	13.08	43.02	4.97
17	-12.29	3.52	30.08	28.35	-21.53
18	-23.29	-3.31	12.08	26.68	-34.03
19	-24.63	-9.31	80.08	97.02	-38.86
20	-19.29	14.19	47.41	90.52	-41.70
21	-19.29	44.19	84.08	101.18	-51.03
22	-18.63	44.19	29.08	18.85	-64.00
23	0.37	15.19	55.74	56.48	-5.00
24	42.71	3.52	28.74	53.98	8.50
25	65.37	32.85	58.61	46.15	42.14
26	71.87	39.19	31.94	5.52	2.80
27	31.21	20.85	43.28	-22.15	8.30
28	7.87	-8.48	19.58	-27.15	-14.70
29	-20.29	-5.31	20.91	-29.82	-28.96

* residuals which exceed the upper limit are underlined

GROUP 2 - Facilities Exceeding the Upper Limit For Residuals (hours/month)*

FACILITY	B125	B158	B169	B180	B181
SQ FEET	593291	74284	171781	46531	69408
QUARTER					
1	55.65	46.15	-21.58	-16.83	-1.49
2	158.65	73.32	0.75	-11.50	2.17
3	196.25	55.38	19.92	-14.83	32.51
4	58.29	61.72	-7.42	-0.67	7.47
5	-37.41	17.22	-4.12	-0.80	10.94
6	-107.58	-3.25	-39.62	9.43	-24.23
7	-34.58	54.22	-39.12	-7.37	-22.39
8	23.55	88.25	-28.75	-9.40	4.81
9	58.75	90.22	-22.08	-12.47	29.01
10	7.75	68.42	11.42	-10.50	37.84
11	-18.78	30.38	18.42	20.17	69.67
12	-43.21	58.05	79.58	40.33	50.14
13	-38.98	67.38	101.08	36.67	45.97
14	-69.28	83.55	78.75	2.83	-14.86
15	-99.95	58.55	43.08	-23.83	38.81
16	-83.68	7.55	26.08	-17.47	40.64
17	-105.55	-2.45	13.42	7.20	44.97
18	-71.88	-1.45	72.52	15.20	-10.69
19	-117.38	3.88	48.32	32.67	-7.03
20	-136.88	-1.12	54.32	12.00	-4.19
21	-149.55	3.45	-8.78	23.17	5.31
22	-115.78	-4.88	-15.58	32.00	2.81
23	-85.78	24.28	34.42	30.67	-10.36
24	-112.45	20.38	235.58	10.83	-13.86
25	-135.21	36.72	286.25	-22.17	24.47
26	-124.55	26.88	275.42	-17.17	58.97
27	-115.71	49.32	75.68	47.33	66.31
28	-61.38	101.72	87.35	90.00	18.31
29	-42.18	94.22	84.72	82.33	-5.36

* residuals which exceed the upper limit are underlined

GROUP 2 - Facilities Exceeding the Upper Limit For Residuals (hours/month)*

FACILITY	B286	B640	B645	B949
SQ FEET	7379	267745	205118	8783
QUARTER				
1	-8.72	142.56	44.93	0.56
2	-8.72	136.39	110.10	12.06
3	-10.72	76.89	77.93	3.39
4	-10.72	121.69	88.77	0.89
5	-8.72	107.86	-6.23	-10.61
6	-8.72	82.86	9.27	-11.27
7	-8.72	41.42	-9.87	-10.94
8	-10.72	36.92	68.63	-9.21
9	-7.39	25.22	120.80	-9.21
10	46.45	-19.48	142.60	35.46
11	51.78	-8.14	95.77	38.73
12	77.95	-24.64	24.87	40.06
13	24.11	26.69	10.20	-3.94
14	19.78	-21.31	-1.63	-8.94
15	-3.39	27.22	8.27	-7.61
16	43.61	-7.44	34.43	6.23
17	42.61	22.56	21.43	12.23
18	36.28	-40.78	11.47	9.56
19	-10.72	-48.11	-21.20	-5.11
20	-10.72	-73.94	-18.53	68.23
21	-10.72	-68.61	-18.07	68.23
22	17.95	-39.11	14.43	68.73
23	19.28	-9.44	8.60	-7.27
24	19.28	45.22	21.27	-7.27
25	7.95	58.79	59.93	-7.94
26	6.61	77.12	113.30	-10.94
27	6.61	71.96	111.80	-10.94
28	-10.72	119.56	50.93	-10.94
29	-10.72	135.89	47.40	-11.27

* residuals which exceed the upper limit are underlined

Appendix K: GROUP 3 - Facilities Exceeding the Upper Limit For Residuals (hours/month)*

FACILITY	B542	B700	B794	B796	B827	B946
SQ FEET	25463	74112	8059	25129	26739	7100
QUARTER						
1	147.05	8.11	30.87	-9.43	8.02	66.60
2	145.38	-9.06	46.37	15.41	28.68	39.10
3	115.72	-37.06	10.37	15.07	18.22	-1.73
4	61.95	-5.39	8.37	-7.26	23.22	-2.73
5	19.45	30.84	0.20	1.71	3.88	-3.06
6	5.92	72.44	13.50	9.57	10.68	-4.93
7	56.22	52.77	13.50	37.57	27.05	-4.10
8	63.05	17.04	24.17	29.44	16.38	33.24
9	56.75	0.11	16.87	21.57	69.25	35.77
10	27.42	6.27	40.87	-2.79	49.22	38.94
11	17.08	66.44	38.20	6.87	74.88	1.60
12	47.58	19.44	44.54	37.37	33.22	-1.73
13	56.25	51.94	21.20	99.91	26.22	-5.73
14	60.92	2.11	5.87	69.57	3.22	30.77
15	66.25	39.77	-5.13	39.57	-20.28	34.44
16	52.25	-25.86	-0.46	-26.93	-23.22	34.77
17	68.42	-32.53	1.37	-31.93	-20.55	2.94
18	63.18	-39.69	5.70	-32.43	-14.72	-0.73
19	65.18	-17.73	11.20	-32.76	-8.78	0.10
20	41.85	8.61	22.04	-32.76	-4.45	2.10
21	24.08	18.44	25.37	-32.76	-15.78	8.44
22	18.42	57.94	25.70	-32.76	-4.05	10.94
23	33.58	100.44	13.04	-32.76	-5.72	4.77
24	58.08	145.94	15.04	-19.59	-0.05	-0.90
25	137.08	127.94	46.87	-12.93	-0.45	-2.90
26	160.45	82.44	156.54	-11.59	4.92	2.60
27	147.28	3.44	156.20	-19.26	-3.08	8.57
28	89.85	-2.76	140.20	-17.43	-15.32	7.57
29	77.82	-7.59	43.20	1.11	20.98	1.57

* residuals which exceed the upper limit are underlined

Bibliography

1. Acker, David D. "Measuring & Managing Quality & Productivity On Defense Programs," Program Manager, 17: 23-29 (July-August 1988).

2. Armstrong, Maj Terry D., Chief of Operations Branch. Personal Interview. 2853 Civil Engineering Squadron, Robins AFB GA, April 1988.

3. Barksdale, Capt George G. To Aspire for Excellence: Analysis of HQ SAC/DE Policy on the Heating, Ventilating, and Air Conditioning (HVAC) Maintenance Program. MS Thesis, Public Administration. University of Oklahoma, Spring 1987.

4. Belt, Cliff. Director for Special Projects. Telephone interview. Rochester Institute of Technology, Rochester NY, 13 January 1989.

5. Braswell, Charles C. and Lewis M. Strong. "Operation, Maintenance: designing for the future," Heating/Piping/Air Conditioning, 59: 69-76 (May 1987).

6. Brown, Edward. "Improving production economics via plant engineering decisions," PIMA, 70: 39-44 (February 1988).

7. Department of the Air Force. Civil Engineering General: Operations Management. AFR 85-2. Washington: HQ USAF, 7 October 1988.

8. Department of the Air Force. Standard Facility Requirements. AFM 86-2. Washington: HQ USAF, 7 October 1988.

9. Dohrmann, D.R. and T Alereza. "Analysis of Survey Data on HVAC Maintenance Costs," ASHRAE TRANSACTIONS PART 2A, 92: 550-565 (1986).

10. Farwell, Robert H. and 1Lt Joe Ballard. "HVAC Improvement Program." Report for LOGM 559, Environmental and Energy Issues. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 26 November 1986.

11. Gibson, Thomas C. "The Total Quality Management Resource," Quality Progress, 20: 62-66 (November 1987).

12. Glazner, Steve. Editor of Facilities Manager. Telephone interview. The Association of Physical Plant Administrators of Universities and Colleges, Alexandria VA, 17 January 1989.

13. Hayes, Roger. Chief of Energy Management. Telephone interview. University of North Carolina, Chapel Hill NC, 10 February 1989.

14. HQ AFESC/CC. "HVAC Improvement Program." CC Letter, 6 March 1985.

15. HQ AFESC/CV. "Improvement of Operating Efficiencies of HVAC Systems (HQ USAF/LEE Ltr, 19 Oct 82)." CV Letter, 8 November 1982.

16. HQ AFESC/DEM. "HVAC Improvement Program." DEM Letter, 19 December 1983.

17. HQ AFESC/DEM. "Improvement of Operating Efficiencies of HVAC Systems." DEM Letter, 4 February 1983.

18. HQ USAF/LEE. "Heating, Ventilating, and Air Conditioning Control Systems (HVAC) Design and Maintainability (HQ USAF/LEEEU Engineering Technical Letter (ETL) 83-1, dtd 16 Feb 83)." LEE Letter, 4 March 1983.

19. HQ USAF/LEE. "Improvement of Operating Efficiencies of HVAC Systems." LEE letter, 19 October 1982.

20. Humphries, James B. "Measuring Maintenance Planning Success," Plant Engineering, 41: 60-64 (8 October 1987).

21. Johnston, Dave. Computer Engineer. Personal interview. HQ AFLC/DEMG, Maintenance Management Division, Wright-Patterson AFB OH, 10 February 1989.

22. Kenworthy, Harry W. "Total Quality Concept: A Proven Path to Success," Quality Progress, 19: 21-24 (July 1986).

23. Klosterman, Mark. Industrial Engineer. HQ AFESC/SIW Information Systems Directorate WIMS, Tyndall AFB FL, 19 April 1989.

24. Knight, Roger, Supervisor of HVAC Controls Unit. Telephone interview. 2853 Civil Engineering Squadron, Robins AFB GA, 2 December 1988.

25. Lenane, Dean-Michael, "Accounting for the Real Cost of Qualit··." Quality Progress, 19: 22-27 (January 1986).

26. McCor ck, Lyle B., Jr. "Measuring Planning and Scheduling Effectiveness," Plant Engineering, 41: 192-194 (12 March 1987).

27. Ott, Lyman. An Introduction to Statistical Methods and Data Analysis (Third Edition). Boston: PWS-KENT Publishing Company, 1988.

28. Reynolds, Daniel E. Class handout distributed in MATH 692, Managerial Statistics II. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, November 1988.

29. Reynolds, Daniel E. Class notes from MATH 692, Managerial Statistics II. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, November 1988.

30. Schmidt, Capt Mike and Chief Master Sergeant James Preacher. Maintenance Engineering Program Manager and Electrical Manager. Personal interview. HQ AFLC/DEMM, Maintenance Engineering Division, Wright-Patterson AFB OH, 31 January 1989.

31. Sherrill, James and Carla Wyrick. Senior Management Analyst and Computer Programmer. Telephone interview. University of Tennessee, Knoxville TN, 25 January 1985.

32. Walton, Mary. The Deming Management Method. Foreword by W. Edwards Deming. New York: The Putnam Publishing Group, 1986.

33. Wentland, Maj Barry. Class notes from EMGT 556, Executive Engineering Management Symposium. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, November 1988.

34. Westerkamp, Thomas A., "How To Test Maintenance Productivity Part II. Administrative and Technical Elements," Plant Engineering, 39: 62-64 (10 October, 1985).

Vita

Tom M. Ellis [redacted] He graduated from high school in Chattanooga, Tennessee, in 1978. In 1982, he received a Bachelor of Science Degree in Mechanical Engineering from Tennessee Technological University. He received his commission in the USAF in October 1982. He was assigned to the Civil Engineering Squadron at Robins AFB, Georgia, where he held positions in design and contract management. In August 1986, he took a position as a civilian contract manager. He was promoted to the position of Chief of Systems Management in May 1987. He continued in this position until entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1988.

[redacted]

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFIT/GEM/DEM/89S-8

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: School of Systems and Logistics

6b. OFFICE SYMBOL (If applicable): AFIT/LSM

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS (City, State, and ZIP Code): Air Force Institute of Technology (AU) Wright-Patterson AFB, OH 45433-6583

7b. ADDRESS (City, State, and ZIP Code):

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State, and ZIP Code):

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification): IDENTIFICATION OF HVAC DEFICIENCIES USING ANALYSIS OF JOB ORDER DATA

12. PERSONAL AUTHOR(S): Tom M. Ellis

13a. TYPE OF REPORT: MS Thesis

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT (Year, Month, Day): 1989 September

15. PAGE COUNT: 108

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
13	01	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Air Force Civil Engineering, Maintenance Management, Air Conditioning Equipment, Repair

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Thesis Advisor: Capt Michael Falino
Instructor of Management Applications
School of Engineering and Services

Approved for public release: IAW AFR 190-1.

Larry W. Emmelhainz

LARRY W. EMMELHAINZ, Lt Col, USAF 11 Oct 89
Director of Research and Consultation
Air Force Institute of Technology (AU)
Wright-Patterson AFB OH 45433-6583

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: Michael Falino, Capt USAF

22b. TELEPHONE (Include Area Code): (513) 255-4552

22c. OFFICE SYMBOL: AFIT/DEM

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Abstract

The objective of this research study was to develop a systematic and objective procedure to identify HVAC deficiencies at Robins AFB, GA. Statistical analysis of HVAC repair data was used to indicate where and when HVAC deficiencies had occurred based on the potential for cost savings. The statistical models which were developed are only applicable to Robins AFB. However, the procedures used to identify HVAC deficiencies could be repeated at any base that maintains historical HVAC repair data. The research also explored the use of the procedures developed as a tool for the HVAC Evaluation Group.

The research showed that job order analysis provided a useful means for identifying HVAC deficiencies. Facility square footage and historical job order data were used to predict the expected number of job order hours within specific facility groups. These groups were established based on similarities among facilities in the HVAC job order data.

The difference between the expected hours and the actual hours was then used to prioritize HVAC d ficiencies based on the potential for reducing job order hours and thus the potential for cost savings.